Water Quality Special Study Report

U.S. Army Corps of Engineers
Omaha District

Assessment of the Water Quality Conditions at Ed Zorinsky Reservoir and the Zebra Mussel (Dreissena polymorpha) Population Emerged after the Drawdown of the Reservoir

And

Management Implications for the District's Papillion and Salt Creek Reservoirs

Aerial Photo of Ed Zorinsky Reservoir with insert photo showing Zebra Mussels

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1 INTRODUCTION

1.1 ED ZORINSKY RESERVOIR (ZORINSKY LAKE)

1.1.1 LOCATION AND DESCRIPTION

Ed Zorinsky Reservoir (Zorinsky Lake) is located in Douglas County in eastern Nebraska. The reservoir is located entirely within the city limits of Omaha, the largest city in the State of Nebraska. The dam that forms Zorinsky Lake is located on Box Elder Creek, a small tributary stream in the West Branch Papillion Creek basin. The dam was completed on July 20, 1984; however, potential water quality problems delayed closure. Two wastewater treatment facilities occasionally discharged to tributaries upstream of the reservoir and it was decided to delay final closure until the situation was addressed. The situation was corrected by constructing a diversion pipeline to the Elkhorn River in the fall of 1989. The low-level gate at the dam was closed on December 7, 1989 and the reservoir reached its initial fill in April 1992.

Table 1-1 gives selected engineering data for Zorinsky Lake. When built, the full multipurpose pool of Zorinsky Lake was 1.5 miles long and had a surface area of 259 acres, a storage capacity of 3,037 ac-ft, and a mean depth of 11.7 feet. The reservoir's watershed is 16.4 square miles, and was largely agricultural when the dam was completed in 1984. However, the watershed has undergone extensive urbanization with the growth of Omaha over the past two decades. It is estimated that about 8-10 percent of the as-built multipurpose pool volume of Zorinsky Lake has been filled from sedimentation.

The reinforced concrete intake structure at the Zorinsky Lake dam has four upper-level intakes (two at invert elevation 1110.0 ft-NGVD29 and two at invert elevation 1117.6 ft-NGVD29), an intermediate-level intake (invert elevation 1104.3 ft-NGVD29), and a low-level intake (invert elevation 1090 ft-NGVD29). The upper-level intakes are uncontrolled. The intermediate-level intake has a 6-inch diameter slide gate for flow augmentation releases for water quality management. The low-level intake is provided with a slide gate to permit draining of the reservoir below elevation 1110.0 ft-NGVD29. The low-level inlet is constructed 240 feet upstream of the intake tower. The inlet is provided with a trash rack and emergency bulkhead to allow closure with the gate open. A 30-inch reinforced concrete pipe connects the low-level inlet to the intake structure. The low-level outlet was installed at the dam to permit draining of the multipurpose pool in approximately a 1-month time period. This outlet may also be used to hasten the evacuation of flood storage so as to avoid damage to shoreline vegetation and recreational facilities. The low-level outlet was also identified for water quality management purposes by providing: 1) downstream flow augmentation releases during low-flow periods, and 2) targeted withdrawal from the bottom of the reservoir. The U.S. Army Corps of Engineers (Corps) has regulated the reservoir largely as a "fill-and-spill" operation.

1.1.2 AUTHORIZED PROJECT PURPOSES

The authorized purposes for the construction of Ed Zorinsky Reservoir were flood control, recreation, fish and wildlife, and water quality. The reservoir has a water quality storage allocation of 620 ac-ft.

Table 1-1. Selected engineering data for Zorinsky Lake.

General		
Dammed Stream	Boxelder Creek	
Drainage Area	16.4 sq. mi.	
Reservoir Length[(1)]	1.5 miles	
Designated Water Quality Storage	620 ac-ft	
Multipurpose Pool Elevation (Top)	1110.0 ft	
Date of Dam Closure	7 Dec 1989[(2)]	
Date of Initial Fill[(3)]	22 Apr 1992	
"As-Built" Conditions[(4)]	(1985)	
Lowest Reservoir Bottom Elevation	1074 ft-NGVD29	
Surface Area at top of Multipurpose Pool	259 ac	
Capacity of Multipurpose Pool	3,037 ac-ft	
Mean Depth at top of Multipurpose Pool[(5)]	11.7 ft	
Surveyed Conditions	(2007:USACE)	(2002:USGS)
Lowest Reservoir Bottom Elevation	1080 ft	1077 ft
Surface Area at top of Multipurpose Pool	247 ac	246 ac
Capacity of Multipurpose Pool	2,781 ac-ft	2,870 ac-ft
Mean Depth at top of Multipurpose Pool[(5)]	11.3 ft	11.7 ft
Sediment Deposition in Multipurpose Pool	(2007:USACE)	(2002:USGS)
Surveyed Sediment Deposition[(6)]	256 ac-ft	167 ac-ft
Annual Sedimentation Rate[(7)]	11.6 ac-ft/yr	9.3 ac-ft
2010 Estimated Sediment Deposition[(8)]	290 ac-ft	242 ac-ft
2010 Capacity of Multipurpose Pool[(9)]	2,747 ac-ft	2,795 ac-ft
Percent of "As-Built" Multipurpose Pool capacity lost to current estimated sediment deposition	10%	8%

Operational Details – Historic	(1991 – 2010)
Maximum Recorded Pool Elevation	1116.8 ft 25-Jul-93
Minimum Recorded Pool Elevation	1091.7 ft 7-Apr-2011
Maximum Recorded Daily Inflow	561 cfs 15-Jun-91
Maximum Recorded Daily Outflow	142 cfs 26-Jul-93
Average Annual Pool Elevation	1109.9 ft
Average Annual Inflow	4,852 ac-ft
Average Annual Outflow	4,151 ac-ft
Estimated Retention Time[(10)]	0.66 Years
Operational Details – 2010[(11)]	
Maximum Recorded Pool Elevation	1112.9 ft 23-Jun-10
Minimum Recorded Pool Elevation	1110.1 ft 4-Oct-09
Maximum Recorded Daily Inflow	288 cfs 21-Jun-10
Maximum Recorded Daily Outflow	84 cfs 23-Jun-10
Total Inflow (% of Average Annual)	10,280 ac-ft (203%)
Total Outflow (% of Average Annual)	9,389 ac-ft (221%)
Outlet Works	
Ungated Outlets	2) 1.5'x3.5' 1110.0 ft 2) 3.2'x8.0' 1117.6 ft
Gated Outlets (Mid-depth)	1) 6" Dia. 1104.3 ft
Gated Outlets (Low-level)	1) 30"x30" 1090.0 ft

Note: All elevations given are in the NGVD29 datum.
(1) Reservoir length at top of multipurpose pool.
(2) Dam completed 15-Jul-1984, low-level gate closed 7-Dec-1989.
(3) First occurrence of reservoir pool elevation to top of multipurpose pool elevation.
(4) "As-built" conditions taken to be the conditions present when the reservoir was first surveyed.
(5) Mean depth = volume ÷ surface area.
(6) Surveyed sediment deposition is the difference in reservoir storage capacity to top of multipurpose pool between "as-built" and survey.
(7) Annualized rate based on historic accumulated sediment.
(8) Accumulated sediment at the end of 2010 estimated from historic annual sedimentation rate.
(9) Capacity of multipurpose pool at the end of 2010 = "As-built" multipurpose pool capacity - estimated 2010 sedimentation.
(10) Estimated retention time = estimated 2010 multipurpose pool volume ÷ average annual outflow.
(11) 2010 operational details are for the water year 1-Oct-2009 through 30-Sep-2010.

1.2 WATER QUALITY AT ZORINSKY LAKE

1.2.1 WATER QUALITY STANDARDS

The State of Nebraska's water quality standards designates the following beneficial uses to Zorinsky Lake: recreation, warmwater aquatic life, agricultural water supply, and aesthetics. The reservoir is not used as a public drinking water supply and has no designated swimming beaches. Zorinsky Lake is one of the most highly visited lake and recreational areas in the State of Nebraska.

1.2.2 SECTION 303(D) IMPAIRMENT LISTING

Pursuant to the Federal Clean Water Act (CWA), the State of Nebraska listed Zorinsky Lake on the State's 2010 Section 303(d) impaired waters list. The beneficial use of aquatic life was identified as impaired. The identified pollutants/stressors included: nutrients (chlorophyll *a*, total nitrogen, and total

phosphorus) and hazard index compounds (mercury – fish tissue). The State of Nebraska has issued a fish consumption advisory for Zorinsky Lake because of mercury concerns. A nutrient and sediment Total Maximum Daily Load (TMDL) was completed for Zorinsky Lake and approved by the U.S. Environmental Protection Agency in September 2002.

1.2.3 WATER QUALITY MONITORING AND MANAGEMENT

The District has monitored ambient water quality conditions at Zorinsky Lake since the reservoir was initially filled in the early 1990's, and currently monitors water quality at Zorinsky Lake as part of an Interagency/Support Agreement with the Nebraska Department of Environmental Quality (NDEQ).

When the Papillion Creek Tributary projects were authorized water quality management was identified as a concern within the Papillion Creek basin. At that time, studies by the Federal Water Pollution Control Administration (FWPCA) indicated that a need existed for water quality storage within the basin. The FWPCA identified the need for 3 cfs water quality flow in the Big Papillion Creek, Little Papillion Creek, and West Branch Papillion Creek. To meet this need, a water quality component was identified in the multipurpose pool for three of the Papillion Creek Tributary projects (i.e., Ed Zorinsky, Glenn Cunningham, and Wehrspann). Each of these three reservoirs was equipped with a mid-level and low-level outlet to facilitate releases for water quality management. Originally, Zorinsky Lake was to have a multipurpose pool of 4,700 ac-ft with a water quality component of 620 ac-ft. The 1984 survey of Ed Zorinsky Reservoir established the "as-built" multipurpose storage of the reservoir at 3,037 ac-ft. To date, releases for downstream water quality management have not been necessary because seepage, releases, and/or tributary inflows have provided adequate flow for water quality purposes.

Since authorized water quality storage has not been required for downstream water quality management, it is available for reservoir water quality management. Zorinsky Lake is dimictic and the near-bottom area of the reservoir becomes anoxic during the summer and winter. Releases could be made from the reservoir through the low-level outlet to discharge poor quality water during these times and replace it with better quality inflow water. Such releases could also promote mixing within the reservoir and possibly improve dissolved oxygen conditions in lower depths when the reservoir is thermally stratified and reduce internal phosphorus loading.

1.3 ZEBRA MUSSELS AT ZORINSKY LAKE

1.3.1 DISCOVERY OF ZEBRA MUSSELS

The European freshwater zebra mussel (*Dreissena polymorpha*) and a congener species, quagga mussel (*Dreissena bugensis)* are invasive species that were introduced to North America in the mid-1980s. These mussels produce a planktonic veliger larval stage (veliger) that eventually settles to the bottom and then uses byssal threads for attachment to firm substrates. They are the only calcareous-shelled invertebrates that attach to firm substratum in freshwater. Their ability to occupy a unique niche makes them an environmental threat and especially problematic as attached biofoulers.

As part of the District's routine maintenance at Zorinsky Lake, the reservoir was lowered 3 feet in the fall of 2010 to pool elevation 1107 ft-NGVD29. This was done to facilitate the placement of additional riprap along the reservoir shoreline for erosion control. On 18-Nov-2010 a Boy Scout was picking up litter along the reservoir shoreline and picked up an aluminum can with a suspected zebra mussel attached. The can and attached suspected zebra mussel were provided to Nebraska Game and Parks Commission (NGPC) officials who confirmed it as a zebra mussel. The District was informed on 24-Nov-2010 of the discovery of the zebra mussel at Zorinsky Lake. During the week of 6-Dec-2010 the

District conducted reconnaissance inspections of Zorinsky Lake and discovered additional zebra mussels near the boat ramp and outlet structure.

Zorinsky Lake is the second verified occurrence of zebra mussels in Nebraska, and the first in a reservoir with significant public access. Zorinsky Lake is the first District project with a verified occurrence of zebra mussels.

1.3.2 INITIAL MEASURES IMPLEMENTED TO CONTROL ZEBRA MUSSELS

The District's Missouri River Project Office convened an interagency meeting on 2-Dec-2010 and the "Zorinsky Lake Zebra Mussel Team" (ZLZMT) was formed. The ZLZMT consisted of members from the City of Omaha, NGPC, NDEQ, Nebraska Department of Agriculture (NDA), Papio-Missouri River Natural Resources District (PMRNRD), Nebraska Invasive Species Project (NISP), and the District. A public information meeting, lead by NISP, was held on 7-Dec-2010 to discuss zebra mussels and the implication to Zorinsky Lake. With input from the public meeting, the ZLZMT recommended that immediate actions be taken to control the zebra mussel population in Zorinsky Lake. At the time, it was concluded that this was likely an initial infestation of zebra mussels and measures should be implemented to control their potential spread from Zorinsky Lake to other area water bodies and protect public infrastructure. An initial measure identified by the ZLZMT for controlling the zebra mussel population at Zorinsky Lake was drawing the reservoir down over the winter. It is generally believed that a rapid drop in water level (i.e., reservoir drawdown) during the winter months, and the subsequent exposure of zebra mussels to sub-freezing temperatures, can result in the mortality of emerged zebra mussels due to freezing and desiccation (McMahon, Ussery, & Clarke, 1993). It was also recommended that Zorinsky Lake remain drawn down until zebra mussel veliger sampling could be completed in the summer of 2011 and chemical treatment pursued if warranted.

At the request of the ZLZMT, an additional seven foot drawdown of Lake Zorinsky began on 10-Dec-2010 with the reservoir reaching a pool elevation of 1100 ft-NVGD29 on 18-Dec-2010. The drawdown to pool elevation 1100 ft-NGVD29 was deemed within the Districts normal operation and regulation of the reservoir. The ZLZMT recommended that a complete drawdown of Zorinsky Lake should be pursued, and an Environmental Assessment (EA) was completed by the District to evaluate this recommendation. On 23-Dec-2010, the low-level outlet gates were opened to draw down Zorinsky Lake to the maximum extent possible. On 4-Jan-2011 Zorinsky Lake reached an elevation of 1092.4 ft-NGVD29 which was the maximum drawdown possible without the removal of accreted sediment in front of the low-level outlet.

1.3.3 SURVEY OF EMERGED ZEBRA MUSSEL SHELLS AFTER THE ZORINSKY LAKE DRAWDOWN

Preliminary inspections just prior to and after the reservoir drawdown indicated a very low abundance of zebra mussels relative to levels reported in the literature for infested waters. To gain a better understanding of the zebra mussel population that was present in Zorinsky Lake at the time of the 2010/2011 winter drawdown, in was decided to survey the exposed bottom of the reservoir for the occurrence of emerged adult zebra mussel shells.

2 ZORINSKY LAKE WATER QUALITY

2.1 WATER QUALITY MONITORING METHODS

2.1.1 AMBIENT WATER QUALITY MONITORING

The District has monitored ambient water quality conditions at Zorinsky Lake since the reservoir was initially filled in the early 1990's. Ambient water quality monitoring locations included sites on the reservoir and on the inflow and outflow of the reservoir. Figure 2-1 shows the location of sites that were monitored for ambient water quality conditions during the 5-year period 2006 through 2010. The near-dam location (i.e., EZRLKND1) has been monitored since 1993.

2.1.1.1 Monitoring Sites, Sample Types, and Collection Frequency

2.1.1.1.1 Reservoir Sites

The reservoir monitoring sites (i.e., EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2) were approximately equally spaced along Zorinsky Lake from near the dam to the inflow of Box Elder Creek (Figure 2-1). The sites were located in the deepest part of the longitudinal area of the reservoir monitored (i.e., over the submerged creek channel). Where the old creek channel had filled with sediment (i.e., upstream of 168th Street), the sites were located in the middle of the reservoir.

Ambient monitoring at the reservoir sites was conducted monthly from May through September. This monitoring included depth-profile measurements in ½-meter increments and measurement of Secchi depth at all reservoir sites. Depth-profiles were measured using a "HydroLab" equipped with a DataSonde 5. Water quality grab samples were collected for laboratory analysis at sites EZRLKND1 and EZRLKUP1. Near-surface grab samples were collected at both sites at a depth of ½ the measured Secchi depth. A near-bottom grab sample (within ½-meter of the reservoir bottom) was also collected at site EZRLKND1. Depth-discrete water samples were collected with a horizontally-oriented Van Dorn sampler.

2.1.1.1.2 Inflow Site

An inflow monitoring site was located on Box Elder Creek at the 192nd Street bridge crossing. Inflow samples were collected during periods of "significant" runoff (i.e., 1-inch rainfall event or a ½-foot or more increase in stream stage from "base-flow" conditions). A near-surface grab sample was collected in an area of faster current. Up to six runoff events were sampled from April through September.

2.1.1.2 Water Quality Parameters Measured and Analyzed

The water quality parameters that were monitored at the reservoir and inflow sites at Zorinsky Lake are given in Table 2-1.

Aerial view of Zorinsky Lake prior to complete 2010/2011 winter drawdown

Figure 2-1. Locations of sites where ambient water quality monitoring was conducted at Zorinsky Lake during the 5-year period 2006 through 2010.

Table 2-1. Parameters monitored at Zorinsky Lake water quality monitoring sites.

Parameter	EZRLKND1 EZRLKUP1		EZRLKML1A EZRLKML1B EZRLKML2 EZRLKUP2	Inflow
	Near Surface	Near Bottom[1]		
Alkalinity, Total	✓	✓		
Carbon, Total Organic	✓	✓		✓
Chlorophyll *a*	✓			
Dissolved Solids, Total	✓			✓
Metals, Dissolved (Fe and Mn)	✓	✓		
Metals, Total (Fe and Mn)	✓	✓		
Microcystins	✓			
Nitrogen, Total Ammonia	✓	✓		✓
Nitrogen, Total Kjeldahl	✓	✓		✓
Nitrogen, Nitrate-Nitrite	✓	✓		✓
Pesticide (Acetochlor, Atrazine, Metolachlor)[2]	✓			✓
Phosphorus, Dissolved	✓	✓		✓
Phosphorus, Ortho-phosphorus	✓	✓		
Phosphorus, Total	✓	✓		✓
Sulfate, Dissolved	✓			
Suspended Solids, Total	✓	✓		✓
Pesticide Scan[2]	✓			
Metals Scan, Total[3]	✓			
Metals Scan, Dissolved[3]	✓			
Secchi Depth	✓		✓	
Phytoplankton	✓			
Profile Measurements[4]	✓		✓	✓[5]

(1) Near-bottom samples collected at site EZRLKND1 only.
(2) One complete pesticide scan in May. Rapid Assay for acetochlor, atrazine, and metholachlor at all times. The complete pesticide scan included: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin.
(3) Only analyzed for in the month of August. Dissolved metals to be analyzed: aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, silver, thallium, and zinc. Total metals to be analyzed: iron, manganese, mercury, and selenium. Hardness was calculated from dissolved calcium and magnesium concentrations.
(4) Profile measurements included: water temperature, dissolved oxygen (mg/l and % sat.), pH, specific conductance, turbidity, oxidation-reduction potential (ORP), and chlorophyll *a*. Profile increment ½-meter.
(5) Measurements taken at near-surface only.

2.1.1.3 Assessment of Ambient Water Quality Data

2.1.1.3.1 Statistical Assessment

Statistical analyses were performed on the ambient water quality monitoring data collected at Zorinsky Lake using the Data Analysis utility in Microsoft Excel. Descriptive statistics were calculated to describe central tendencies (mean and median) and the range (minimum and maximum) of the data collected over the 5-year period 2006 through 2010. The relative abundance of phytoplankton based on

biovolume was determined from seasonal samples collected in 2010. Water quality trends were determined for water clarity (i.e. Secchi depth), total phosphorus, chlorophyll *a*, and trophic state index (TSI) from monitoring results obtained at site EZRLKND1 for the 19-year period 1992 through 2010. The TSI was calculated as described by Carlson (1977). Scatter plots were prepared by plotting the four parameters over the 19-year period, and a linear regression trend line was determined. Analysis of variance (ANOVA) was used to determine an R^2 value and to test for the significance ($\alpha = 0.05$) of a linear trend over time.

2.1.1.3.2 Spatial Variation in Water Quality Conditions

2.1.1.3.2.1 Reservoir Longitudinal Contour Plots

Longitudinal water quality contour plots were constructed for Zorinsky Lake. Contour plots were constructed for temperature, dissolved oxygen, pH, oxidation-reduction potential (ORP), and turbidity from depth-profile measurements collected along the length of the reservoir. The longitudinal contour plots were constructed using the "Hydrologic Information Plotting Program" included in the "Data Management and Analysis System for Lakes, Estuaries, and Rivers" (DASLER-X) software developed by HydroGeoLogic Inc. (HydroGeologic, Inc., 2005).

2.1.1.3.2.2 Reservoir Depth-Profile Plots

Measured water temperature, dissolved oxygen, pH, and ORP depth profiles were plotted for the for the near-dam monitoring site of Zorinsky Lake over the 5-year period 2006 through 2010. The plots were reviewed to assess the occurrence of thermal stratification, hypoxic dissolved oxygen conditions, and general water quality variation with depth.

2.1.2 WINTER 2010/2011 WATER QUALITY MONITORING

Water quality monitoring was conducted at Zorinsky Lake during the 2010/2011 winter. At the maximum 2010/2011 winter drawdown elevation of 1092.4 ft- NGVD29 there was still impounded water remaining in Zorinsky Lake. The reservoir was ice-covered with flowing water at the inflow to the lowered pool just downstream of 168th Street and at the outflow to the low-level gate near the dam. Initial reconnaissance monitoring at the low-level outlet indicated dissolved oxygen levels below 50 percent saturation. This indicated that there likely was significant oxygen demand being exerted by the wetted sediments in the reservoir at the time. It was determined that monitoring water quality in the reservoir under these conditions could facilitate future quantification of sediment oxygen demand. Also, a concern existed as to whether the impounded water in Zorinsky Lake offered a refugia for zebra mussels to survive the winter drawdown and serve as potential "seed stock" to re-infest the reservoir when eventually refilled.

2.1.2.1 <u>Monitoring Sites, Sample Types, Collection Frequency, and Methods</u>

2.1.2.1.1 Inflow and Outflow Sites

Site EZRLK168NF was established to monitor water quality conditions of the water flowing directly into the lowered pool of Zorinsky Lake during the 2010/2011 winter. Site EZRLK168NF was located under the 168th Street bridge (Figure 2-2). Box Elder Creek was sampled once in late January at site EZRNF1 at the 192nd Street bridge (Figure 2-1). Two outflow monitoring sites were established, site EZRLKOUT1 at the inflow to the low-level outlet gate and site EZRRL1 downstream of the dam where water daylights to Box Elder Creek after flowing through the dam and stilling basin (Figure 2-2). Water quality conditions at the inflow and outflow sites were sampled from 28-Jan to 24-Feb.

Aerial view of Zorinsky Lake on 22-Feb-2011 after the complete 2010/2011 winter drawdown

Figure 2-2. Locations of sites where water quality monitoring was conducted at Zorinsky Lake during the 2010/2011 winter.

At all inflow and outflow sites a HydroLab equipped with a DataSonde 5 was used to measure near-surface water quality conditions. These measurements included temperature, dissolved oxygen, specific conductance, pH, ORP, turbidity, and chlorophyll *a*. At site EZRLKOUT1 one water sample was collected for laboratory analysis. The parameters analyzed included: alkalinity, ammonia, total Kjeldahl nitrogen, nitrate-nitrite, phosphorus (dissolved and total), ortho-phosphorus, total suspended solids, and chlorophyll *a*.

2.1.2.1.2 Reservoir Sites

Reservoir sites monitored during the 2010/2011 winter were at the ambient reservoir monitoring locations that remained submerged within the drawn down reservoir pool – EZRLKND1, EZRLKML1A, EZRLKML1B, and EZRLKML2 (Figure 2-2). Depth profiles were measured at these sites during late January and early February. No reservoir profiles were measured after 11-Feb due to unsafe ice conditions.

At all reservoir sites a hole was drilled through the ice with an ice augur. A HydroLab equipped with a DataSonde 5 was used to measure a depth profile from the ice surface to the reservoir bottom in 1-foot increments. Depth profiles were measured for temperature, dissolved oxygen, specific conductance, pH, ORP, turbidity, and chlorophyll *a*.

2.1.2.2 Assessment of Winter 2010/2011 Water Quality Data

2.1.2.2.1 Statistical Assessment

Statistical analyses were performed on the 2010/2011 winter water quality monitoring data collected at Zorinsky Lake. Descriptive statistics were calculated to describe central tendencies (mean and median) and the range (minimum and maximum) of the data collected over the 5-week period 28-Jan through 24-Feb-2011.

2.1.2.2.2 Estimation of Chlorophyll *a* Concentrations from Field Measurements

The HydroLab and DataSonde5 field monitoring equipment used was equipped with a probe that utilized an in-situ fluorescence sensor to measure chlorophyll *a* presence in millivolts (mV). The mV readings give a relative indication of the amount of chlorophyll *a* present at sampled locations assuming environmental factors remain relatively constant. The field measured mV readings are converted to chlorophyll *a* concentrations by simultaneously collecting a water sample and analyzing it for chlorophyll *a*. The paired measures for chlorophyll *a*, mV and ug/l, are used to determine a ratio that was utilized to convert the mV measurements to ug/l. Typically, a laboratory measured chlorophyll *a* value is regularly determined for conversion of chlorophyll *a* field measurements. However, for the 2011 winter monitoring of Zorinsky Lake only one chlorophyll *a* laboratory measurement was taken to convert field measured chlorophyll *a* values. One paired chlorophyll *a* laboratory sample and field measurement were taken at site EZRLKOUT1 on 28-Jan. The laboratory measured chlorophyll *a* value was 4 ug/l and the field measurement was 0.0145 mV. This resulted in a conversion factor of 275 x mV = chlorophyll *a* concentration in ug/l. This conversion factor was used to estimate chlorophyll *a* concentrations at all the sites where chlorophyll *a* was measured in the field as mV.

2.1.2.2.3 Spatial Variation in Water Quality Conditions

2.1.2.2.3.1 Reservoir Longitudinal Contour Plots

Longitudinal water quality contour plots were constructed for temperature, dissolved oxygen, specific conductance, pH, ORP, turbidity, and chlorophyll *a* from depth-profile measurements collected

during the winter. The longitudinal contour plots were constructed using the "Hydrologic Information Plotting Program" included in the "Data Management and Analysis System for Lakes, Estuaries, and Rivers" (DASLER-X) software developed by HydroGeoLogic Inc. (HydroGeologic, Inc., 2005).

2.1.2.2.3.2 Reservoir Depth-Profile Plots

Measured water temperature, dissolved oxygen, specific conductance, pH, ORP, and chlorophyll *a* depth profiles were plotted for the reservoir sites monitored during the winter. The plots were reviewed to assess the occurrence of thermal stratification, hypoxic dissolved oxygen conditions, and general water quality variation with depth.

2.2 **WATER QUALITY MONITORING RESULTS**

2.2.1 EXISTING WATER QUALITY (2006 THROUGH 2010)

2.2.1.1 Statistical Summary

Water quality conditions that were monitored in Zorinsky Lake at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 from May through September during the 5-year period 2006 through 2010 are summarized in Plate 1 through Plate 5. A review of these results indicated possible water quality concerns regarding dissolved oxygen, nutrients, and chlorophyll a.

A significant number of dissolved oxygen measurements throughout Zorinsky Lake were below the 5 mg/l criterion for the protection of warmwater aquatic life (Plate 1 - Plate 5). All of the low dissolved oxygen measurements occurred near the bottom of the reservoir and were associated with thermal stratification. The following provision is included in Nebraska's Water Quality Standards regarding the application of water quality criteria to lakes:

> *"In lakes and impoundments, or portions thereof, which exhibit natural thermal stratification, all applicable narrative and numerical criteria, with the exception of the numerical criteria for temperature, apply only to the epilimnion."*

This provision seemingly applies to the low dissolved oxygen levels measured in Zorinsky Lake. Therefore, the measured dissolved oxygen levels below 5 mg/l are not considered exceedances of the water quality standards criterion.

Nutrient criteria defined by Nebraska for Section 303(d) water quality assessment include: total phosphorus (50 ug/l), total nitrogen (1,000 ug/l), and chlorophyll *a* (10 ug/l). All three of these assessment criteria were exceeded throughout Zorinsky Lake (Plate 1 - Plate 5). The total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 78, 60, and 72% of the samples collected at site EZRLKND1 (i.e., near-dam) (Plate 1). At site EZRLKUP1 (i.e., upper reaches), the total phosphorus, total nitrogen, and chlorophyll *a* criteria were respectively exceeded by 92, 68, and 72% of the collected samples (Plate 5). All the chlorophyll *a*, total nitrogen, and total phosphorus samples were collected during the "growing season" (i.e., May through September) and the reported mean values represent the growing season average for the 5-year period 2006 through 2010. Based on the State of Nebraska's impairment assessment methodology, the total phosphorus, total nitrogen and chlorophyll *a* mean values all indicate impairment of the aquatic life beneficial use of Zorinsky Lake due to nutrients. The monitored low dissolved oxygen levels in Zorinsky Lake are likely influenced by the existing high nutrient levels.

2.2.1.2 Thermal Stratification

2.2.1.2.1 Longitudinal Temperature Contour Plots

Late-spring and summer thermal stratification of Zorinsky Lake measured during 2009 and 2010 is depicted by longitudinal temperature contour plots constructed along the length of the reservoir. Plate 6 and Plate 7, respectively, provide longitudinal temperature contour plots based on depth-profile temperature measurements taken from May through September at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2009 and 2010. Significant thermal stratification occurred in Zorinsky Lake from late-spring through most of the summer during 2009 and 2010. A 1° to 9°C difference between surface and bottom water temperature was measured.

2.2.1.2.2 Near-Dam Temperature Depth-Profile Plots

The depth-profile temperature measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer thermal stratification of Zorinsky Lake (Plate 8). The plotted depth-profile temperature measurements indicate that the reservoir exhibits significant thermal stratification during the summer. The deeper areas of the reservoir, in the area of the old creek channel, do not appear to mix with the upper column of water during the summer. Since Zorinsky Lake ices over in the winter, it appears to be a dimictic lake based on the measured thermal stratification (Wetzel, 2001). Wetzel (2001) identifies lakes as dimictic if they circulate freely twice a year in the spring and fall and are directly stratified in the summer and inversely stratified under ice cover in winter.

2.2.1.3 Dissolved Oxygen Conditions

2.2.1.3.1 Longitudinal Dissolved Oxygen Contour Plots

Dissolved oxygen contour plots were constructed along the length of Zorinsky Lake based on depth-profile measurements taken during 2009 and 2010. Plate 9 and Plate 10, respectively, provide longitudinal dissolved oxygen contour plots based on depth-profile measurements taken from May through September in 2009 and 2010. Hypoxic conditions (i.e., < 2-3 mg/l dissolved oxygen) were monitored near the reservoir bottom throughout the summer of both years (Plate 9 and Plate 10).

2.2.1.3.2 Near-Dam Dissolved Oxygen Depth-Profile Plots

The depth-profile dissolved oxygen measurements collected during the summer over the past 5 years at the deep water area near the dam were compiled and plotted to describe the existing summer dissolved oxygen conditions of Zorinsky Lake (Plate 11). Most of the plotted profiles indicate a significant vertical gradient in dissolved oxygen levels with most tending towards a clinograde distribution. A few of the plotted profiles indicate dissolved oxygen concentrations above 5 mg/l from the reservoir surface to the bottom. These profiles were measured in early spring or fall and are believed to be a result of thermal stratification breaking down to the depth the profile was measured as "spring turnover" ended or "fall turnover" of the reservoir approached.

2.2.1.3.3 Estimate of Reservoir Volume with Low Dissolved Oxygen Conditions

The volume of Zorinsky Lake with low dissolved oxygen conditions was estimated from the longitudinal dissolved oxygen contour plots constructed for 2009 and 2010 and the District's current Area-Capacity Tables for the reservoir. The constructed contour plots were reviewed to identify the "worst-case" dissolved oxygen condition. The "worst-case" condition was taken to be the contour plot

with the highest elevations of the 5 mg/l and 2.5 mg/l dissolved oxygen isopleths. The July 13, 2010 contour plot indicates a pool elevation of 1111.5 ft-NGVD29, a 5 mg/l dissolved oxygen isopleth elevation of about 1107 ft-NGVD29, and a 2.5 mg/l dissolved oxygen isopleth elevation of about 1102 ft-NGVD29 (Plate 10). The current District Area-Capacity Tables (2007 Survey) give storage capacities of 3,168 ac-ft for elevation 1111.5 ft-NGVD29, 2,104 ac-ft for elevation 1107 ft-NGVD29, and 1,217 ac-ft for elevation 1102 ft-NGVD29. On July 13, 2010 it is estimated that 66% of the volume of Zorinsky Lake was less than the 5 mg/l dissolved oxygen criterion for the protection of warmwater aquatic life, and 38% of the reservoir volume was hypoxic.

2.2.1.4 Water Quality Conditions Based on Hypoxia

Since the dissolved oxygen levels monitored in Zorinsky Lake indicated hypoxic conditions were prevalent throughout the summers of 2009 and 2010, longitudinal contour and depth-profile plots were constructed for oxidation-reduction potential (ORP) and pH. Near-surface and near-bottom water quality samples collected when hypoxia was present were also compared for several analyzed parameters.

2.2.1.4.1 Oxidation-Reduction Potential

Plate 12 and Plate 13, respectively, provide longitudinal ORP contour plots based on measurements taken in 2009 and 2010. The negative ORP values measured by mid- to late-summer in 2010 indicate significant reduced conditions present near the reservoir bottom. Plate 14 plots depth profiles for ORP measured during the summer over the past 5 years in the deep water area of Zorinsky Lake near the dam. A significant vertical gradient in ORP regularly occurred in the reservoir during the summer.

2.2.1.4.2 pH

Longitudinal contour plots for pH conditions measured in 2009 and 2010 are provided, respectively, in Plate 15 and Plate 16. Photosynthesis in the shallower water and reduced conditions in the deeper water of Zorinsky Lake seemingly lead to higher pH levels near the surface and lower pH levels near the reservoir bottom. The highest and lowest measured pH levels were within the Nebraska water quality standards' criteria of ≥ 6.5 and ≤ 9.0 for the protection of warmwater aquatic life. Plate 17 plots depth profiles for pH measured during the summer over the past 5 years in the deep water area of Zorinsky Lake near the dam. A significant vertical gradient in pH regularly occurred in the reservoir during the summer.

2.2.1.5 Water Clarity

2.2.1.5.1 Secchi Transparency

Figure 2-3 displays a box plot of the Secchi depth transparencies measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 during the 5-year period 2006 through 2010 (note: the monitoring sites are oriented in an upstream to downstream direction on the x-axis). Secchi depth transparencies at sites EZRLKUP2 and EZRLKUP1 were similar and appreciably lower than the Secchi depth transparencies at sites EZRLKML2, EZRLKML1B, EZELKML1A, and EZRLKND1 (i.e., non-overlapping inter-quartile ranges). Secchi depths measured at sites EZRLKML2, EZRLKML1B, EZRLKML1A, and EZRLKND1 were similar. The 168th street Bridge separates Zorinsky Lake into an upper and a lower basin (Figure 2-1). The upper basin acts as a "wet" sediment retention trap for the lower basin. Sites EZRLKUP2 and EZRLKUP1 are in the upper basin, while sites EZRLKML2, EZRLKML1B, EZRLKML1A, and EZRLKND1 are in the lower basin.

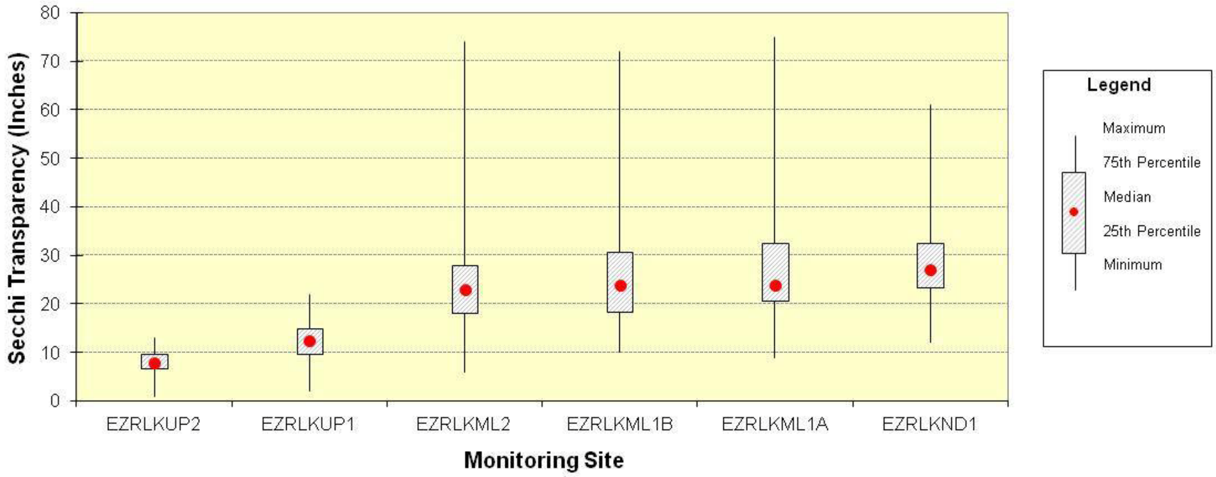


Figure 2-3. Box plot of Secchi depth transparencies measured in Zorinsky Lake during the 5-year period 2006 through 2010. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)

2.2.1.5.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Turbidity contour plots were constructed along the length of Zorinsky Lake based on depth-profile measurements taken during 2009 and 2010. Plate 18 and Plate 19, respectively, provide longitudinal turbidity contour plots based on depth-profile measurements taken from May through September. The measured turbidity levels in Zorinsky Lake varied longitudinally with higher turbidity occurring in the upper reaches of the reservoir. Some vertical variation in turbidity was also measured. Turbidity was also impacted by episodic runoff events.

2.2.1.6 Reservoir Trophic Status

Trophic State Index (TSI) values for Zorinsky Lake were calculated from monitoring data collected during the 5-year period 2006 through 2010 at the near-dam ambient monitoring site (i.e., EZRLKND1). TSI values were determined from Secchi depth transparency, total phosphorus, and chlorophyll *a* measurements (Carlson, 1977). Table 2-2 summarizes the TSI values calculated for the reservoir. The TSI values indicate that the near-dam lacustrine area of Zorinsky Lake is in a eutrophic condition.

Table 2-2. Summary of Trophic State Index (TSI) values calculated for Zorinsky Lake for the 5-year period 2006 through 2010.

TSI*	No. of Obs.	Mean	Median	Minimum	Maximum
TSI(SD)	24	63	65	47	74
TSI(TP)	25	59	60	48	64
TSI(Chl)	25	69	73	46	83
TSI(Avg)	25	64	65	52	72

* TSI(SD), TSI(TP), and TSI(Chl) are TSI index values based, respectively, on Secchi depth, total phosphorus, and chlorophyll *a* measurements. TSI(Avg) is the average of TSI values for the individual parameters.

2.2.1.7 <u>Phytoplankton Community</u>

Phytoplankton grab samples were collected monthly (June through September) from Zorinsky Lake at two sites (EZRLKND1 and EZRLKUP1) during the summer of 2010. Taxa identified in the collected phytoplankton samples were from seven taxonomic divisions: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). The relative abundance of phytoplankton, based on biovolume, in the samples collected from Zorinsky Lake in 2010 is shown in Figure 2-4. Diatoms (Bacillariophyta) were the most dominant phytoplankton group present in Zorinsky Lake. Major phytoplankton species sampled in Zorinsky Lake during 2010 (i.e., genera comprising more than 10% of the total biovolume of at least one sample) included the Bacillariophyta *Aulacoseria granulata and Synedra delicatissima*; Chlorophyta *Chlamydomonas spp.;* Cryptophyta *Cryptomonas spp.* and *Rhodomonas minuta(var. nannoplanctica)*; and Cyanobacteria *Anabaena spp., Aphanizomenon flos-aquae,* and *Cylindrospermopsis raciborskii*.

Phytoplankton chlorophyll *a* levels monitored at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, and EZRLKUP1 over the 5-year period 2006 through 2010 ranged from non-detectable (<1 ug/l) to 152 ug/l (Plate 1 through Plate 5). As discussed earlier, the mean chlorophyll *a* concentration at all the sites was greater than 10 ug/l which is the criterion identified by the State of Nebraska for listing a water body as impaired for aquatic life pursuant to Section 303(d) of the Federal Clean Water Act. No concentrations of the cyanobacteria toxin microcystin above 1 ug/l were monitored in Zorinsky Lake during the 5-year period 2006 through 2010 (Plate 1 and Plate 5).

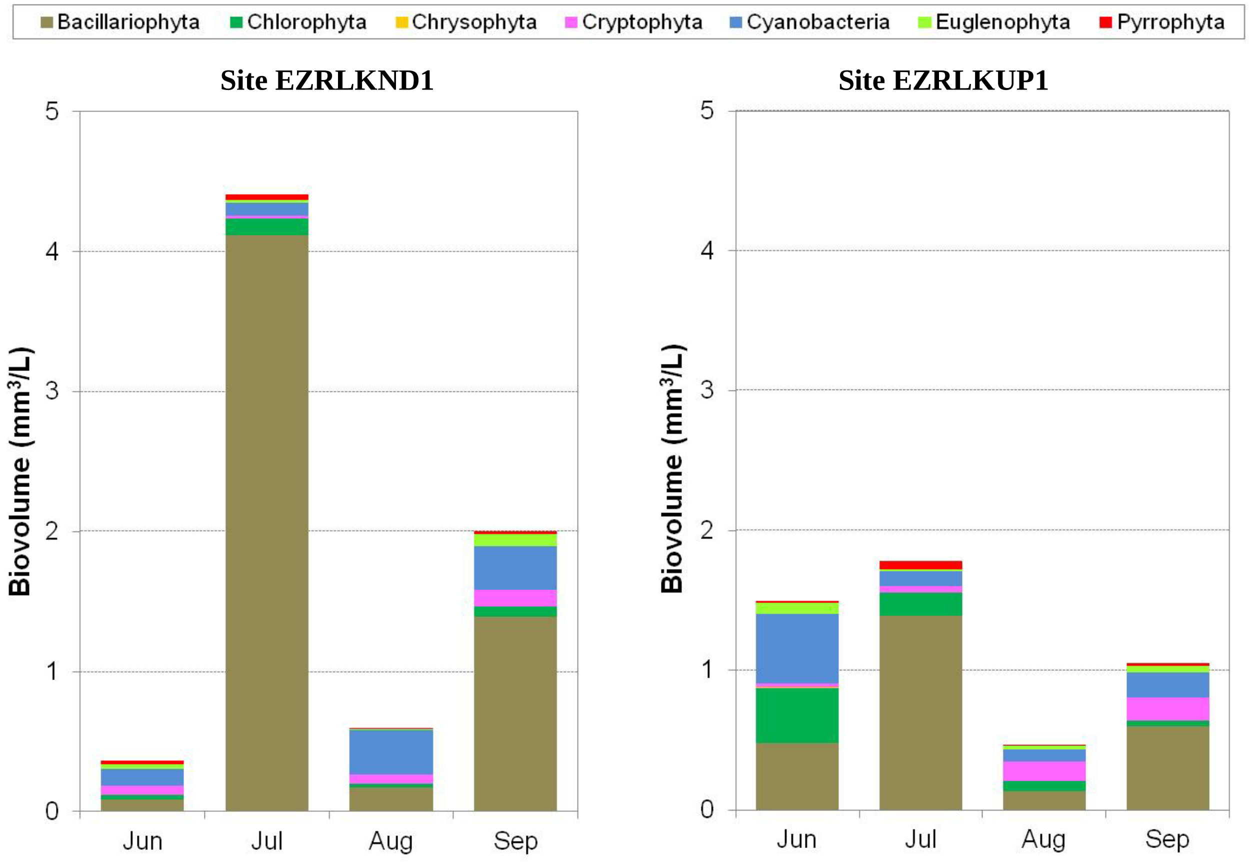


Figure 2-4. Relative abundance of phytoplankton in samples collected from Zorinsky Lake at sites EZRLKND1 and EZRLKUP1 in 2010.

2.2.2 WATER QUALITY TRENDS (1993 THROUGH 2010)

Zorinsky Lake reached initial fill in 1992 and water quality monitoring of the reservoir began in 1993. Water quality trends from 1993 to 2010 were determined for Zorinsky Lake for transparency (i.e., Secchi depth), total phosphorus, chlorophyll *a*, and TSI (i.e., trophic condition). The assessment was based on near-surface sampling of water quality conditions in the reservoir during the months of May through October at the near-dam monitoring site (i.e., EZRLKND1). Plate 20 displays a scatter-plot of the collected data for the four parameters, a linear regression line, and the significance of the trend line (i.e., $\alpha = 0.05$). For the assessment period, Zorinsky Lake exhibited significant trends for Secchi depth (decreasing), chlorophyll *a* (increasing), and TSI (increasing). No significant trend was detected for total phosphorus. Over the 18-year period since 1993, Zorinsky Lake has generally remained in a eutrophic condition. However, if the current trend continues, the reservoir appears to be moving towards a hypereutrophic condition.

2.2.3 WINTER 2011 WATER QUALITY CONDITIONS

2.2.3.1 Outflow Water Quality Conditions

Water quality conditions at outflow sites EZRLKOUT1 and EZRRL1 were monitored on 28-Jan, 4-Feb, 11-Feb, 16-Feb, 18-Feb, and 24-Feb. A summary of the water quality conditions monitored at site EZRLKOUT1 and EZRRL1 are given, respectively, in Table 2-3 and Table 2-4.

Table 2-3. Summary of water quality conditions monitored at site EZRLKOUT1 during the period 28-Jan-2011 to 24-Feb-2011.

Parameter	Monitoring Results					
	Detection Limit[(A)]	No. of Obs.	Mean	Median	Min.	Max.
Discharge (cfs)	0.1	7	21.1	6.0	2.7	48.0
Water Temperature (°C)	0.1	7	2.2	2.3	1.1	3.0
Dissolved Oxygen (mg/l)	0.1	7	5.7	5.4	1.7	9.7
Dissolved Oxygen (% Sat.)	0.1	7	41.9	41.2	13.2	71.0
Specific Conductance (uS/cm)	1	7	823	836	587	1,042
pH (S.U.)	0.1	7	6.8	6.7	6.4	7.3
Oxidation-Reduction Potential (mV)	1	7	308	327	214	417
Turbidity (NTUs)	1	7	102	81	32	185
Chlorophyll *a* (ug/l) – Field Measured[(B)]	1	7	9	7	4	14
Chlorophyll *a* (ug/l) – Lab Determined	1	1	4	4	4	4
Alkalinity, Total (mg/l)	7	1	309	309	309	309
Nitrogen, Ammonia Total (mg/l)	0.02	1	1.13	1.13	1.13	1.13
Nitrogen, Kjeldahl Total (mg/l)	0.1	1	2.5	2.5	2.5	2.5
Nitrogen, Nitrate-Nitrite Total (mg/l)	0.02	1	0.20	0.20	0.20	0.20
Nitrogen, Total (mg/l)	0.1	1	2.7	2.7	2.7	2.7
Phosphorus, Dissolved (mg/l)	0.02	1	0.03	0.03	0.03	0.03
Phosphorus, Total (mg/l)	0.02	1	0.29	0.29	0.29	0.29
Phosphorus-Ortho, Dissolved (mg/l)	0.02	1	0.02	0.02	0.02	0.02
Suspended Solids, Total (mg/l)	4	1	213	213	213	213

(A) Detection limits given for the parameters Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Turbidity are resolution limits for field measured parameters.

(B) Estimated value see Section 2.1.2.2.2 for explanation.

Table 2-4. Summary of water quality conditions monitored at site EZRRL1 during the period 28-Jan-2011 to 24-Feb-2011.

Parameter	Monitoring Results					
	Detection Limit[A]	No. of Obs.	Mean	Median	Min.	Max.
Water Temperature (°C)	0.1	7	2.2	2.3	1.3	3.1
Dissolved Oxygen (mg/l)	0.1	7	9.4	9.2	7.1	11.7
Dissolved Oxygen (% Sat.)	0.1	7	69.9	70.7	54.1	85.7
Specific Conductance (uS/cm)	1	7	846	836	622	1,070
pH (S.U.)	0.1	7	6.8	7.0	6.4	7.1
Oxidation-Reduction Potential (mV)	1	7	336	385	198	508
Turbidity (NTUs)	1	7	119	68	35	222
Chlorophyll *a* (ug/l) – Field Measured[B]	1	7	8	8	4	12

[A] Detection limits given for the parameters Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Turbidity are resolution limits for field measured parameters.

[B] Estimated value see Section 2.1.2.2.2 for explanation.

2.2.3.2 Inflow Water Quality Conditions

Water quality conditions at inflow site EZRLK168NF were monitored on 28-Jan, 4-Feb, 11-Feb, and 24-Feb. Water quality conditions at inflow site EZRNF1 were monitored on 28-Jan. A summary of the water quality conditions monitored at site EZRLK168NF are given in Table 2-5. The water quality conditions monitored at site EZRNF1 on 28-Jan were: water temperature, 0.2°C; dissolved oxygen, 12.8 mg/l and 92.3% saturation; specific conductance, 869 uS/cm; pH, 7.7 SU; ORP, 373 mV; turbidity, 7 NTU; and chlorophyll *a*, 4 ug/l.

Table 2-5. Summary of water quality conditions monitored at site EZRLK168NF during the period 28-Jan-2011 to 24-Feb-2011.

Parameter	Monitoring Results					
	Detection Limit[A]	No. of Obs.	Mean	Median	Min.	Max.
Water Temperature (°C)	0.1	4	0.1	0.1	0.0	0.1
Dissolved Oxygen (mg/l)	0.1	4	10.6	10.3	9.6	12.2
Dissolved Oxygen (% Sat.)	0.1	4	76.1	73.5	67.3	90.1
Specific Conductance (uS/cm)	1	4	1,245	1,120	846	1,892
pH (S.U.)	0.1	4	7.2	7.2	6.9	7.5
Oxidation-Reduction Potential (mV)	1	4	207	198	187	246
Turbidity (NTUs)	1	4	112	52	33	311
Chlorophyll *a* (ug/l) – Field Measured[B]	1	4	3	3	2	5

[A] Detection limits given for the parameters Water Temperature, Dissolved Oxygen (mg/l and % Sat.), Specific Conductance, pH, Oxidation-Reduction Potential, and Turbidity are resolution limits for field measured parameters.

[B] Estimated value see Section 2.1.2.2.2 for explanation.

2.2.3.3 Reservoir Water Quality Conditions

2.2.3.3.1 Depth Profiles

Depth profiles were measured at the four reservoir sites EZRLKND1, EZRLKML1A, EZRLKML1B, and EZRLKML2 on 4-Feb and 11-Feb, and at site EZRLKND1 on 28-Jan. The depth profiles that were measured on 28-Jan, 4-Feb, and 11-Feb are given, respectively, in Plate 21, Plate 22,

and Plate 23. Depth profile plots of the lowered Zorinsky Lake pool for temperature, dissolved oxygen, pH, ORP, specific conductance, turbidity, and chlorophyll *a* measured through the ice on 28-Jan, 4-Feb, and 11-Feb are shown in (Plate 24).

2.2.3.3.2 Longitudinal Contour Plots

Longitudinal contour plots of the lowered Zorinsky Lake pool for temperature, dissolved oxygen, pH, ORP, specific conductance, turbidity, and chlorophyll *a* are shown in Plate 25 through Plate 38. The contour plots are based on the depth profiles collected through the ice at Zorinsky Lake on 4-Feb and 11-Feb. Typical of an ice-covered lake, the lowered pool of Zorinsky Lake was inversely stratified with colder water near the ice surface and warmer water near the reservoir bottom (Plate 25 and Plate 26). The lowered pool was largely hypoxic, with only a small area of water near the inflow having dissolved oxygen levels above 5 mg/l (Plate 27 and Plate 28). The pH levels in the lowered pool ranged from 6.5 to 7.0 SU (Plate 29 and Plate 30). ORP levels ranged from 300 to 110 mV, with higher levels near the ice surface and lower levels near the reservoir bottom (Plate 31 and Plate 32). Specific conductance showed significant vertical variation, with higher levels near the reservoir bottom (Plate 33, and Plate 34). The specific conductance levels in Zorinsky Lake during the winter were likely influenced by runoff from salted streets, and may have allowed for some "salinity-induced" density stratification under the ice cover. Turbidity levels in the lowered pool of Zorinsky Lake were generally higher near the inflow (Plate 35 and Plate 36). Chlorophyll *a* levels showed significant vertical variation, with higher levels near the ice cover and lower levels near the reservoir bottom (Plate 37 and Plate 38). The vertical variation in chlorophyll *a* is attributed to light attenuation.

2.2.3.3.3 Reservoir Flushing from Snowmelt

Over the 1-week period 12-Feb to 18-Feb the substantial snow cover in the Zorinsky Lake watershed had largely melted and was flowing through Zorinsky Lake. During this period the pool elevation of Zorinsky Lake increased from 1092.4 to 1093.7 ft-NGVD29 and a discharge flow of 45 cfs was measured at the low-level outlet. Based on current reservoir capacity tables, Zorinsky Lake at elevation of 1092.4 ft-NGVD29 has a storage volume of 243 ac-ft, and 326 ac-ft at elevation of 1093.7 ft-NGVD29. A flow of 45 cfs would discharge 89.3 ac-ft in a 24-hour period. At these flows, the 243 ac-ft volume of Zorinsky Lake would have been flushed in about 2.7 days. At a volume of 326 ac-ft and a flow of 45 cfs, the residence time of Zorinsky Lake is 3.6 days. It should be noted that water flow through a reservoir takes the "path-of-least-resistance" and travels as under-, over-, and intra-flow. Thus, some water moves through the reservoir more rapidly than other water. Residence time is a mathematical concept and flushing does not necessarily mean that all "old" water has been replaced with "new" water.

Photos 1 and 2 are observed conditions of the Zorinsky Lake releases to Box Elder Creek on 14-Feb and 18-Feb during the snowmelt flushing of the reservoir. As can be seen in Photos 1 and 2, the water was turbid and foaming. The turbidity indicates that bottom sediments were likely being scoured from the reservoir and being passed through the dam outlet to Box Elder Creek. The foaming is likely attributed to "foaming agents" that reduce the surface tension of water, and the agitation at the outlet caused bubbling and foam creation. During anaerobic conditions (as were monitored during the winter in Zorinsky Lake) microorganisms decompose organic matter into lower molecular weight fatty acids and alcohols. Lower molecular fatty acids are good foaming agents. Seemingly, these substances were being released from Zorinsky Lake during the flushing, and the agitation at the release resulted in bubble formation and the accumulation of foam.

Photo 1. Zorinsky Lake releases to Box Elder Creek on 14-Feb-2011.

Photo 2. Zorinsky Lake releases to Box Elder Creek on 18-Feb-2011.

2.2.3.4 **Winter Fish Kill**

As indicated by water quality monitoring of Zorinsky Lake during ice cover, the lowered pool was largely hypoxic, with only a small area of water near the inflow having dissolved oxygen levels above 5 mg/l. Most fish need dissolved oxygen levels above 5 mg/l to survive extended periods. During the winter, numerous dead fish were observed in Zorinsky Lake under the ice cover and in Box Elder Creek downstream of the dam outlet. At ice out numerous dead fish were observed floating in the lowered Zorinsky Lake. Many large, dead catfish were noted floating in Zorinsky Lake immediately after ice out along the south shoreline in the middle of the reservoir. The only area where fish seemingly could have survived the winter in the lowered reservoir was a small area near the inflow of Box Elder Creek. Fish could have moved upstream into Box Elder Creek out of the reservoir to avoid poor water quality conditions.

2.2.3.5 **Water Quality Impacts from Urban Runoff**

Specific conductance levels seven times the historical average of 450 uS/cm were monitored in the lowered Zorinsky Lake during the winter (Plate 33, and Plate 34). The high specific conductance levels are believed to indicate elevated salinity levels attributed to winter runoff from salted streets. Specific conductance was monitored on Box Elder Creek at sites EZRNF1 (192nd Street) and EZRLK168NF (168th Street) on 28-Jan. Site EZRNF1 is approximately 2 miles upstream of site EZRLK168NF in a less urbanized area, while site EZRLK168NF is in a highly urbanized area (Figure 2-1). The specific conductance levels measured at sites EZRNF1 and EZRLK168NF on 28-Jan were, respectively 869 and 1,892 uS/cm. Seemingly, runoff from salted streets significantly raised specific conductance levels in the lowered Zorinsky Lake. The impact to Zorinsky Lake under normal pool levels may be lessened due to dilution provided by the greater reservoir volume.

2.3 **WATER QUALITY DISCUSSION**

Water quality monitoring indicates that Zorinsky Lake is eutrophic and will become hyper-eutrophic if trends continue. The State-defined impairment criteria for total phosphorus, total nitrogen, and chlorophyll *a* were all exceeded and confirm the State's 303(d) listing of Zorinsky Lake as impaired for aquatic life. Zorinsky Lake experiences significant thermal stratification during the summer and, given its eutrophic state, experiences hypoxic to anoxic conditions in the reservoir's hypolimnion. The thermal stratification and hypoxia in Zorinsky Lake result in significant vertical gradients in oxidation-reduction potential and pH during the summer. Turbidity and suspended solids levels in Zorinsky Lake are significantly impacted by episodic runoff. Diatoms were the most abundant phytoplankton group present in Zorinsky Lake; however, periodic cyanobacteria blooms occur. No microcystin levels above 1 ug/l were monitored in the reservoir.

Typical of an ice-covered lake, water quality monitoring indicated the winter 2010/2011 lowered pool of Zorinsky Lake was inversely stratified. The lowered pool was largely hypoxic, with only a small area of water near the inflow having dissolved oxygen levels above 5 mg/l. The specific conductance levels in Zorinsky Lake during the winter were likely influenced by runoff from salted streets. Specific conductance levels seven times the historical average of 450 uS/cm were monitored in the lowered Zorinsky Lake during the winter

3 REVIEW OF ZEBRA MUSSEL OCCURRENCE, BIOLOGY, ENVIRONMENTAL REQUIREMENTS, AND WATER QUALITY IMPACTS

3.1 ZEBRA MUSSEL OCCURRENCE

Zebra mussels are native to the Black, Caspian, and Azov Seas (Benson & Raikow, 2012). They were originally described in the late 1770's by the famous Russian scientist and explorer Pyotr Simon Pallas from a population in a tributary of the Ural River in the Caspian Sea Basin (US Army Corps of Engineers, 2002). During the 19th century zebra mussels spread west from Russia into most of Europe as commercial navigation expanded and canal systems were constructed (US Army Corps of Engineers, 2002). They were first discovered in Britain in 1824 (Benson & Raikow, 2012). Zebra mussels first appeared in North America in 1988 when they were found in Lake St. Clair (Hebert, Muncaster, & Mackie, 1989). The mussels were likely transported to the Great Lakes in the freshwater ballast of a transatlantic ship. As of 2012, zebra mussels have been found in the following states: Alabama, Arkansas, California, Colorado, Connecticut, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New York, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota (unconfirmed), Tennessee, Texas, Utah, Vermont, West Virginia, and Wisconsin (Benson & Raikow, 2012). The successful spread of zebra mussels can be largely attributed to two biological attributes, high fecundity and free swimming larva, which have allowed for its passive dispersal and rapid colonization of an ecological niche where there is little competition.

3.2 ZEBRA MUSSEL BIOLOGY

3.2.1 LIFE CYCLE

As depicted in Figure 3-1, there are three main phases in the zebra mussel life cycle: 1) larval free-living, planktonic veligers; 2) settled juveniles; and 3) largely sessile adults (US Army Corps of Engineers, 2002; Cummings & Graf, 2009). The planktonic veligers range from about 0.1 mm to about 0.5 mm in size and feed on small plankton (Cummings & Graf, 2009; US Army Corps of Engineers, 2002). Depending on water temperature and food availability, veligers take about 1-9 weeks to complete development and settle to the substratum (Cummings & Graf, 2009). However, variation in development time can be significant, with the amount of time required for a fertilized egg to develop into a settled juvenile mussel reported to be as short as 8 days or as long as 240 days (Cummings & Graf, 2009). Given their small size, veligers are easily carried by currents within rivers and lakes, and transported in wetted compartments and obscure areas of boats and boat trailers. Dispersal to areas with no hydraulic connection is often due to human interaction.

Zebra mussel settlement behavior presents two distinct opportunities for substrate selection (Marsden & Lansky, 2000). A post-veliger mussel first contacts a substrate when it becomes too heavy to maintain a planktonic existence and settles out of the water column. This stage may be postponed by re-suspension of post-veligers in the water column and subsequent drifting; juveniles up to 2 mm long have been found in the plankton (Martel, 1993). Upon contact with substrate, the post-veliger may begin to lay down byssal threads secreted through the foot to attach to the substrate or may crawl around, for a few hours to a few days, in search of alternate habitat (Marsden & Lansky, 2000). The juvenile stage is characterized by the transition from a clam-like appearance to the appearance of an adult zebra mussel. Juveniles range in size from 1 to 6 mm and their growth rate varies considerably based on environmental conditions (US Army Corps of Engineers, 2002). The juvenile stage ends and mussels are considered adults when they become sexually mature (i.e., capable of gametogenesis).

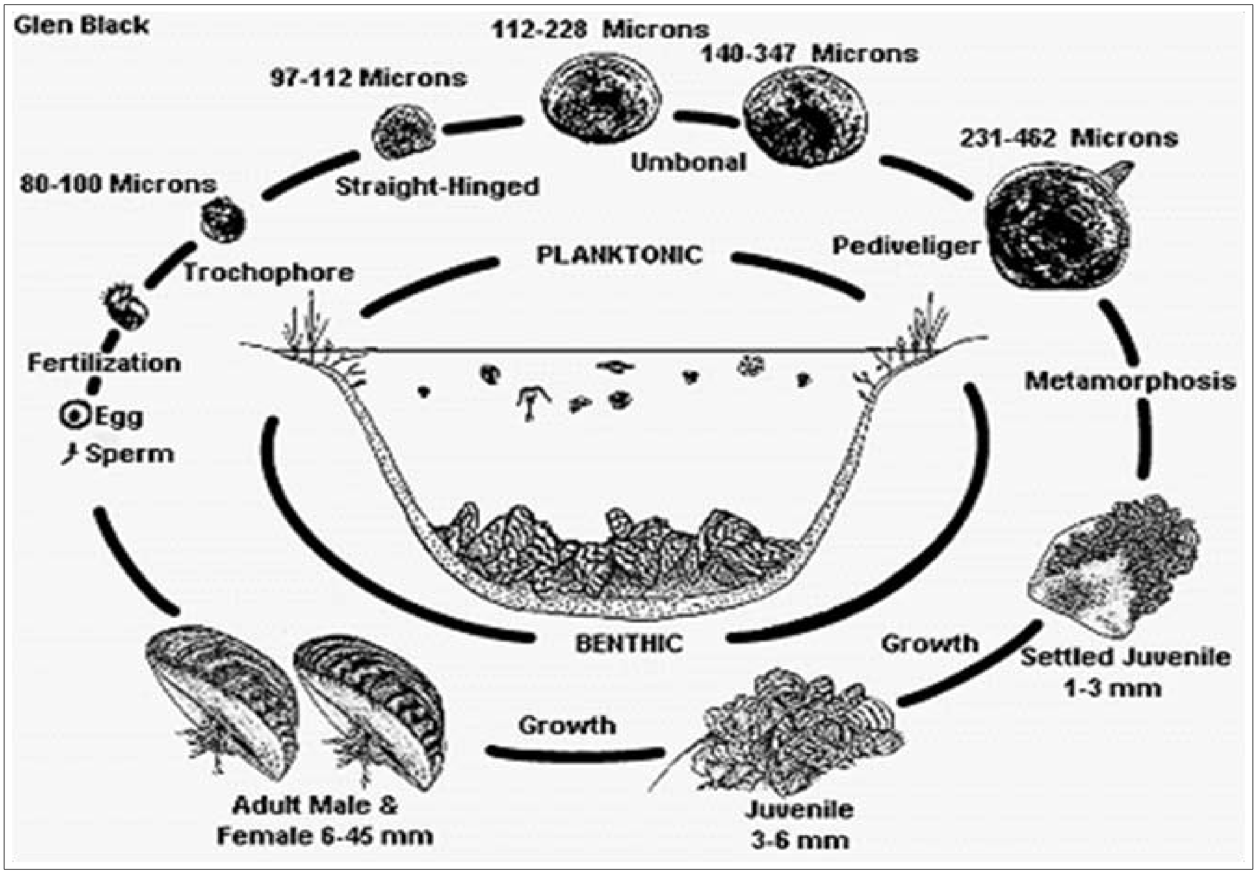


Figure 3-1. Depiction of the zebra mussel life cycle (US Army Corps of Engineers, 2002).

Adult zebra mussels range in size from 6 to 45 mm and generally live to be 2 to 4 years old, but have been reported to live several years (Mackie G. L., 1991; Akcakaya & Baker, 1998; US Army Corps of Engineers, 2002; Cummings & Graf, 2009). They are typically found attached to hard substrates where they use siphons to filter food particles from the water. Adults are largely sessile, but do possess the ability to detach and move in response to environmental change. Detached adult zebra mussels have been found to move up to 48 cm/hr, with smaller individuals generally moving greater distances than larger ones (Toomey, McCabe, & Marsden, 2002). During adulthood zebra mussels expand most of their energy on growth and reproduction.

3.2.2 REPRODUCTIVE BIOLOGY

Although hermaphroditism occasionally occurs, most adult zebra mussels are dioecious and fertilization occurs externally in the water column (Cummings & Graf, 2009). They have an annual reproductive cycle and typically spawn one or more times a year in the late spring or early summer (Cummings & Graf, 2009). Spawning can be a highly synchronized event, focused over a 1-2 week period, or can be completely non-synchronized, occurring throughout the year (Cummings & Graf, 2009). Zebra mussels are almost always capable of reproducing (i.e., initiating gametogenesis) within their initial 12 months of life and spawning in their in their second year (US Army Corps of Engineers, 1994; McMahon R. F., 1996; US Army Corps of Engineers, 2002; Cummings & Graf, 2009; Benson & Raikow, 2012). The zebra mussel undergoes an annual cycle of gonad growth and gamete maturation, culminating in one or more spawning events in late spring or early summer (Ram, Fong, & Garton, 1996). Under natural thermal regimes, gonad development begins in the fall with gametogenesis continuing through the

winter until spawning occurs in the following spring and summer (Benson & Raikow, 2012; US Army Corps of Engineers, 1994; Ram, Fong, & Garton, 1996; Gist, Miller, & Brence, 1997). A single adult zebra mussel can release over 40,000 eggs in a spawning event and up to one million in a spawning season (Benson & Raikow, 2012; Mackie & Schloesser, 1996). Synchronization of spawning and the concurrent release of gametes are stimulated by factors such as serotonin, pheromones, temperature, photoperiod, food availability, and the effects of neighboring mussels (Ram, Fong, & Garton, 1996; Cummings & Graf, 2009). Zebra mussel spawning in North America likely begins at water temperatures of 12°C and reaches a peak at water temperatures of 15-18°C (Claudi & Mackie, 1994; McMahon R. F., 1996; Benson & Raikow, 2012; Cummings & Graf, 2009). Gametogensis is inhibited at temperatures approaching 30°C (Cummings & Graf, 2009).

3.3 ZEBRA MUSSEL ECOLOGY

3.3.1 POPULATION DENSITIES

Natural population densities of zebra mussels can range from <100 to >100,000 mussels/m^2 and densities of 5,000 to 30,000/m^2 are not uncommon (Hebert, Muncaster, & Mackie, 1989; Mackie G. L., 1991; McMahon, Ussery, & Clarke, 1993; Mellina, Rasmussen, & Mills, 1995; Idrisi, Mills, Rudstam, & Stewart, 2001; US Army Corps of Engineers, 2002; Benson & Raikow, 2012). Zebra mussel densities as high as 700,000/m^2 were found in pipes at a power plant in Michigan (Benson & Raikow, 2012).

3.3.2 POPULATION DEMOGRAPHICS

Strayer and Malcom (2006) identify five possible long-term trajectories for an invasive zebra mussel population (Figure 3-2). First, zebra mussel populations can follow a boom-bust cycle, with high population densities for a few years after colonization, followed by much lower densities over the long-term. Second, zebra mussel populations can show cyclic behavior driven by the dominance of strong year-classes. Third, populations of zebra mussels might be more or less in equilibrium after their initial establishment, fluctuating from year to year but showing no long-term pattern in population density. Fourth, the population might show no long-term trends, but show large, irregular fluctuations in population density. Finally, zebra mussel populations might expand only after a long lag phase as has been described for other invasive species. Populations that are simply space-limited may be relatively stable, unless the population is so dense that large areas of zebra mussel beds die and slough off synchronously as a result of overcrowding (Chase & Bailey, 1999). Space-limited zebra mussel populations are perhaps most likely to occur in small lakes, where hard substrata are scarce and phytoplankton is abundant (Strayer & Malcom, 2006).

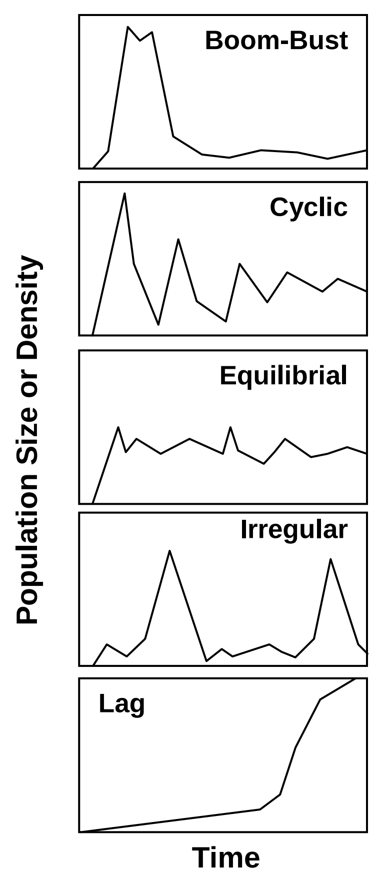


Figure 3-2. Five possible long-term trajectories for populations of zebra mussels (Strayer & Malcom, 2006).

Akcakaya and Baker (1998) developed a growth model based on zebra mussel population density and size structure data provided by the Corps. The data were collected from several lotic systems, including the Illinois River, Upper Mississippi River, and lower Ohio River. Some of these data followed cohorts of various sizes that were measured (i.e., shell length) biweekly *in situ* from June 1 to October 1. These data indicated that zebra mussel growth rates were greatest in the first year and steadily decreased thereafter with age. Based on these data, the following zebra mussel growth rates were modeled for the upper Mississippi River : 0-1 year (0-16 mm), 1-2 year (17-27 mm), 2-3 year (28-35mm), > 3 year (>35 mm).

3.4 ZEBRA MUSSEL LIMITING FACTORS AND ENVIRONMENTAL HABITAT REQUIREMENTS

Limiting factors are environmental factors that limit population sizes in a particular ecosystem. When zebra mussels are introduced into a water body, their chances of establishing a viable and problematic population are dependent on the characteristics of the new habitat. Generally, a zebra mussel population will thrive as long as there are: 1) hard substrates for the mussels to settle on and attach to, 2) appropriate physical and chemical conditions in the water, and 3) adequate food resources (US Army Corps of Engineers, 2002). Unsuitable environmental conditions can limit zebra mussel populations within a water body (Strayer & Malcom, 2006; Farr & Payne, 2010). The long-term trajectory of a zebra mussel population depends on the extent to which environmental factors limit the population (Strayer & Malcom, 2006). As zebra mussel population densities increase they can alter the physical and biological characteristics of the water body they inhabit (MacIsaac, 1996; US Army Corps of Engineers, 2002; Benson & Raikow, 2012)

Environmental habitat conditions play a key role in the establishment and abundance of zebra mussel populations. Several water quality, physical, and biological factors have been identified as critical in determining the viability of zebra mussel populations. These factors include: temperature, pH, calcium, dissolved oxygen, turbidity, sunlight, substratum, food availability, and predation (US Army Corps of Engineers, 2002; Strayer & Malcom, 2006; Farr & Payne, 2010).

3.4.1 WATER QUALITY FACTORS

3.4.1.1 Water Temperature

Zebra mussels are ectothermic (i.e., cold blooded) and temperature plays an important role in the timing and rate of biological processes such as metabolism, growth, and reproduction. Due to its role in the regulation of biological activity, water temperature is an important constraint on the viability of zebra mussels. The upper incipient lethal limit for temperature for North American populations has been found to be ~30°C (McMahon, Matthews, Ussery, Chase, & Clarke, 1995). Survival above 30°C is possible for short time periods with gradual temperature increase and prior acclimation to warm temperatures (Farr & Payne, 2010). Freezing temperatures are not well tolerated by zebra mussels, and mortality of individual mussels occurs within 15 hours of aerial exposure to temperatures of ~1.5°C (Clarke, 1993 as cited in (Farr & Payne, 2010). Figure 3-3 depicts selected temperatures that have important biological effects on zebra mussels.

3.4.1.2 pH

Zebra mussels are less tolerant of low pH than native North America bivalves (McMahon R. F., 1996). Environmental pH affects the rate at which some biochemical reactions occur in zebra mussels and can be an important factor when determining their environmental requirements (Farr & Payne, 2010). Minimum pH limits are 6.5 S.U. for adult zebra mussels and 7.4 S.U. for veligers (McMahon R. F.,

1996). It has been found that high pH levels (> 9.3 S.U) cannot be tolerated by zebra mussels (Hincks & Mackie, 1997; Bowman & Bailey, 1998). Figure 3-3 depicts selected pH levels that have important biological effects on zebra mussels.

3.4.1.3 Calcium

Sufficient calcium concentrations are necessary for shell growth and osmo-regulation for zebra mussel survival (Hincks & Mackie, 1997; Farr & Payne, 2010). Calcium concentrations of 15 mg/l or less are believed to limit the distribution of zebra mussels in North America (Mellina & Rassmussen, 1994). Zebra mussels can survive at lower calcium levels (< 15 mg/l); however, the mussels lose calcium to the external medium and juvenile growth rates are impacted because there is not enough calcium for shell building (Hincks & Mackie, 1997). Moderate to high densities of zebra mussels are often associated with concentrations of greater than 21 mg/l calcium (Mellina & Rassmussen, 1994; Hincks & Mackie, 1997), although some field data indicate a decline in zebra mussel biomass at concentrations greater than 25 mg/l (Jones & Ricciardi, 2005). Figure 3-3 depicts selected calcium levels that have important biological effects on zebra mussels.

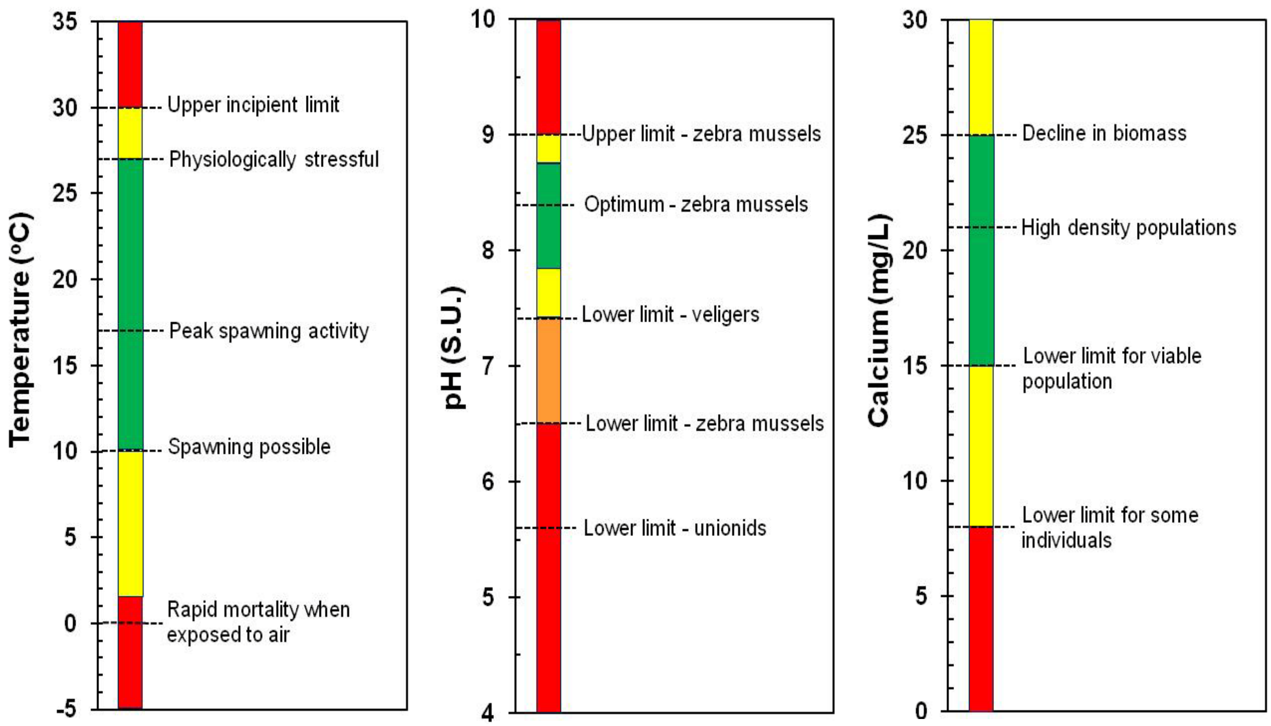


Figure 3-3. Important biological effects of temperature, pH, and calcium on zebra mussels. [Modified from (Farr & Payne, 2010).]

3.4.1.4 Dissolved Oxygen (DO)

Zebra mussels are clean-water inhabitants and are usually found where DO is greater than 90% saturation, and are stressed in water with less than 40 to 50% saturation (Boelman, Neilson, Dardeau, & Cross, 1997). They are generally less tolerant of low DO conditions then native North American bivalve species (McMahon R. F., 1996). Estimates of the lowest DO concentrations in which zebra mussels can survive range from 1 to 4 mg/l (Farr & Payne, 2010). Variability in experimental design and mussel

condition prevents the accurate estimate of a lower lethal limit (Farr & Payne, 2010). A critical threshold of 25% DO saturation appears necessary for survival; however, adult zebra mussels can survive anaerobic conditions for short periods with sensitivity to oxygen deprivation inversely related to size (McMahon R. F., 1996; Karatayev, Burlakova, & Padilla, 1998). The overall sensitivity of zebra mussels to low DO probably limit their ability to thrive in eutrophic or highly polluted environments (Farr & Payne, 2010).

3.4.1.5 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Turbidity is an indirect estimate of the concentration of particles suspended in the water column. Elevated turbidity levels could be beneficial or detrimental to zebra mussels depending of the source of the turbidity. Turbidity due to elevated phytoplankton could indicate an abundant food source, while turbidity due to suspended inorganic material could indicate conditions that interfere with filter-feeding, respiration, and survival. Zebra mussels demonstrate the ability to filter seston from the water column which can enhance water clarity and result in temporal changes in turbidity and energy flow (MacIsaac, 1996; Herbert, Wilson, & Murdoch, 1991). Strayer (1991) examined data from 30 Europeon lakes and found that zebra mussels were often absent from habitats where Secchi disk depths were less than 1 meter. However, higher Secchi depth measurements in less turbid environments could reflect seston clearing by zebra mussels rather than a limiting factor (Farr & Payne, 2010). Alexander et al. (1994) found that increasing levels of inorganic turbidity (bentonite clay) lowered the respiratory response (Vo_2) in zebra mussels. The respiratory response was not further decreased with increasing turbidity, but it could play a role in slowing zebra mussel growth rates (Alexander, Thorp, & Fell, 1994).

3.4.2 PHYSICAL FACTORS

3.4.2.1 Sunlight

Zebra mussels appear to be photosensitive and avoid sunlight when possible (Marsden & Lansky, 2000). Mardsen and Landsky (2000) found that zebra mussels showed a preference for shaded versus sunlight surfaces based on colonization of deployed settlement plates in nearshore areas of Lake Michigan. Mussels preferred the upper side of plates over the underside, and over vertical surfaces, but they strongly avoided sunlight areas (Marsden & Lansky, 2000). Where they have been surveyed in lentic enviroments, adult zebra mussels occurrence is less abundant at near surface depths (Mackie & Schloesser, 1996; Idrisi, Mills, Rudstam, & Stewart, 2001). Zebra mussel veligers exhibit diurnal movement, with maximum densities occurring near the surface during early morning and at lower depths during the day (Mackie & Schloesser, 1996). The avoidance of near surface depths by zebra mussels could be a result of photosensitivity; howerver, low zebra mussel densities in shallow areas in lakes can also be attributed to wave action and ice scour (MacIsaac, 1996; Strayer & Malcom, 2006).

3.4.2.2 Substratum

Zebra mussels are most often associated with hard, stable substrata where they attach using byssal threads. Firm substratum is usually required for initial establishment (Farr & Payne, 2010). Mussel density has been shown to positively correlate with substrate particle size in the St. Lawrence River (Mellina & Rassmussen, 1994). Due to the oxygen demand that can be associated with silt substratum, dissolved oxygen requirements can also limit zebra mussel survival on silt substratum [(Karatayev, Burlakova, & Padilla, 1998) and references therein]. Zebra mussel population densities in lakes with uniform soft sediment are less likely to reach the population density or ubiquity of lakes dominated by

coarse-grain substratum (Farr & Payne, 2010). The greatest cause of mortality during the settling stage (99%) is settlement on unsuitable substrates (Benson & Raikow, 2012).

3.4.3 BIOLOGICAL FACTORS

3.4.3.1 Food Availability and Preference

Zebra mussels feed primarily on planktonic algae and zooplankton, but other suspended material filtered from the water column (bacteria, detritus, organic matter) can be a nutritional source (US Army Corps of Engineers, 2002; Benson & Raikow, 2012). When food resources are limiting, intraspecific competition within a zebra mussel population for food can probably be a significant mortality factor and a major density-dependent, population-regulating mechanism (US Army Corps of Engineers, 2002). Adult zebra mussels in high-density populations, for example, may compete with their planktonic larvae for limited food resources, thus reducing survival of their planktonic larvae (US Army Corps of Engineers, 2002). Strayer et al. (1996) provided evidence that adult zebra mussels outcompeted their pelagic larvae for phytoplankton in the Hudson River and suggested that such food-limited zebra mussel populations may be especially frequent in rivers and estuaries, where ratio of food supply to available substratum is small.

Laboratory investigations have indicated that food quality may be a better indicator of environmental conditions suitable for zebra mussel growth than food quantity (Schneider, Madon, Stoeckel, & Sparks, 1998). They found that the association between feeding processes and food quality appears related to a breakdown in the ability of zebra mussels to selectively ingest high-quality organic particles when the organic content of the seston is low. These results suggest that the conditions of high suspended inorganic sediment concentration represent a difficult growth environment for zebra mussels. Food availability is believed to play a role in determining the frequency of zebra mussel spawning (Ram, Fong, & Garton, 1996; Gist, Miller, & Brence, 1997)

Zebra mussels feed by filtering particles of variable size (0.7-1.2 μm) from the water column and can efficiently sort particles for ingestion (Ten Winkel & Davids, 1982; Horgan & Mills, 1997; Baker, Levinton, Kurdziel, & Shumway, 1998; Cummings & Graf, 2009). Large, low quality food and unpalatable particles are bound in mucus and expelled as pseudofeces through the inhalant siphon (Ten Winkel & Davids, 1982). Zebra mussels positively select particles with lengths and diameters of 15-45 μm, and negatively select smaller or larger particles (Ten Winkel & Davids, 1982). A large part of the phytoplankton consumed by zebra mussels in Lake Maarsseveen, The Netherlands, was diatoms; however, the biflagellate cryptomonads *Cryptomonas spp.* were highly preferred as food (Ten Winkel & Davids, 1982). The cyanobacteria *Microcystis* was the preferred food source in the Hudson River (Baker, Levinton, Kurdziel, & Shumway, 1998). In a meso-eutrophic lake in Sweden, selective grazing by zebra mussels varied in relation to seasonal phytoplankton dyanamics, and showed a consistent preference for cryptophytes and avoidance of chlorophytes and cyanobacteria (Naddafi, Pettersson, & Eklov, 2007). Zebra mussel grazing is believed to promote *Microcystis* blooms in low nutrient North American Lakes (Vanderploeg, et al., 2001; Raikow, Sarnelle, Wilson, & Hamilton, 2004). Zebra mussels have both negative (consumption) and positive (altered nutrient availability) impacts on *Microcystis* (Raikow, Sarnelle, Wilson, & Hamilton, 2004; Sarnelle, Wilson, Hamilton, Knoll, & Raikow, 2005). In low nutrient lakes, grazing of phytoplankton by zebra mussels, including consumption of *Microcystis*, may alter nitrogen and phosphorus fluxes by moving enough nutrients from the water column to the benthos that *Microcystis* blooms can occur (Bykova, Laursen, Bostan, Bautisa, & McCarthy, 2006; Raikow, Sarnelle, Wilson, & Hamilton, 2004; Sarnelle, Wilson, Hamilton, Knoll, & Raikow, 2005). Another possible mechanism is the rejection and excretion of ingested toxic cyanobacteria as pseudofeces by zebra mussels that enhances toxic cyanobacteria levels (Juhel, et al., 2006).

3.4.3.2 Predation

A review of the international literature in the mid-1990's identified 176 species as predators of zebra mussels (Molloy, Karatayev, Burlakova, Kurandina, & Laruelle, 1997). The majority of species identified as predators of attached zebra mussels in North America are birds or fish (Molloy, Karatayev, Burlakova, Kurandina, & Laruelle, 1997; Kirk, Killgore, & Sanders, 2001). However, the crayfish (*Orconectes rusticus)* has been documented to prey on zebra mussels (Perry, Lodge, & Lamberti, 2000). Numerous North America fish species have been documented to prey on attached zebra mussels (Table 3-1). Only a small number of North American fish species have been confirmed as consumers of veligers; however, this might be due do to difficulties in detecting them in gut contents. North American fish species that have been found to consume veliger larvae are also listed in Table 3-1.

A big unknown when a new invasive species becomes established in a water body is how it will fit into the indigenous food web. When zebra mussels invade new systems and become abundant, fish can shift their prey use to these mollusks if they can be ingested and enough energy can be obtained from the food source to support their growth and metabolic needs. Recent North American studies have indicated that fish in some locales are using zebra mussels as a food source. Magoulick & Lewis (2002) found that predation by blue catfish (*Ictalurus furcatus*), freshwater drum *(Aplodinotus grunniens)*, and redear sunfish *(Lepomis microlophus)* significantly reduced the density of mussels larger than 5 mm in Lake Dardenelle, Arkansas; however, the impact to smaller mussels was less clear. They found that zebra mussels were the primary prey eaten by 52% of blue catfish, 48% of freshwater drum, and 100% of adult reaear sunfish. Blue catfish showed distinct seasonal prey shifts, feeding on zebra mussels in summer and shad (*Dorsoma* spp.) during the winter. USGS (2011) found that five fish species, redhorse suckers (*Moxostoma spp.*), common carp (*Cyprinus carpio*), bluegill (*Lepomis macrochirus*), quillback carpsucker (*Carpiodes cyprinus*), and flathead catfish (*Pylodictis olivaris)* preyed on zebra mussels in the upper Mississippi River with redhorse suckers (59%) and common carp (35%) having the highest frequency of predation. Watzin et al. (2008) found that freshwater drum, pumpkinseed (*Lepomis gibbosus*), yellow perch (*Perca flavescens*), and rock bass (*Amplodinotus grunniens*) all consumed zebra mussels at varying frequencies and amounts in Lake Champlain, New York/Vermont/Quebec. Tucker et al. (1996) found that common carp (*Cyprinus carpio*) fed extensively on zebra mussels in the Mississippi River at RM 217.

Table 3-1. Documented fish predation on zebra mussels in North America.

Species	Common Name	Reference
Fish Predation on Zebra Mussel Veligers		
Alosa aestivalis	Blueback herring	(Limburg & Ahrend, 1994)
Alosa pseudoharengus	Alewife	(Mills, O'Gorman, Roseman, Adams, & Owens, 1995)
Dorosoma cepedianum	Gizzard shad	(Mills, O'Gorman, Roseman, Adams, & Owens, 1995)
Morone Americana	White perch	(Limburg & Ahrend, 1994)
Osmerus mordax	Rainbow smelt	(Mills, O'Gorman, Roseman, Adams, & Owens, 1995)
Fish Predation on Attached Zebra Mussels		
Acipenser brevirostrum	Shortnose sturgeon	Bain, M. B. as cited by Molloy, 1997
Acipenser fulvescens	Lake sturgeon	(French, 1993)
Ambloplites rupestris	Rock bass	(Watzin, Joppe-Mercure, Rowder, Lancaster, & Bronson, 2008)
Ameriurus nebulosus	Brown Bullhead	(Kirk, Killgore, & Sanders, 2001)
Aplodinotus grunniens	Freshwater drum	(French, 1993) (Magoulick & Lewis, 2002) (Watzin, Joppe-Mercure, Rowder, Lancaster, & Bronson, 2008)
Carpiodes cyprinus	Quillback carpsucker	(US Geological Survey, 2011)
Catostomus commersoni	White sucker	(French, 1993)
Coregonus clupeaformis	Lake whitefish	(French, 1993)
Cyprinus carpio	Common carp	(Tucker, C, Soergel, & Theiling, 1996) (US Geological Survey, 2011)
Ictalurus nebulosus	Brown bullhead	(French, 1993)
Ictalurus furcatus	Blue catfish	(Magoulick & Lewis, 2002)
Lepomis auritis	Redbreast sunfish	Schmidt, R. as cited by Molloy, 1997
Lepomis gibbosus	Pumpkinseed	(French, 1993) (Watzin, Joppe-Mercure, Rowder, Lancaster, & Bronson, 2008)
Lepomis macrochirus	Bluegill	(US Geological Survey, 2011)
Lepomis microlophus	Redear sunfish	(Magoulick & Lewis, 2002)
Morone Americana	White perch	(French, 1993)
Morone chrysops	White bass	(French, 1993)
Moxostoma valenciennesi	Greater redhorse	(French, 1993) (US Geological Survey, 2011)
Neogobius melanostomus	Round goby	Jude et al., as cited by Molloy, 1997
Nocomis raneyi	Bull chub	(Kirk, Killgore, & Sanders, 2001)
Perca flavescens	Yellow perch	(French, 1993) (Watzin, Joppe-Mercure, Rowder, Lancaster, & Bronson, 2008)
Percopsis omiscomaycus	Trout Perch	(Kirk, Killgore, & Sanders, 2001)
Pylodictis olivaris	Flathead Catfish	(US Geological Survey, 2011)
Stizostedion vitreum	Walleye	(French, 1993)

Table modified from Molloy et al., (1997) and Kirk et al., (2001)

3.5 ZEBRA MUSSEL WATER QUALITY IMPACTS

A number of processes that are associated with dense populations of zebra mussels have significant potential to impact water quality. These include the high filtration rates required for feeding, high excrement rates associated with nonselective filtration and selective retention, increased nutrient cycling, and respiration-based demand for dissolved oxygen (US Army Corps of Engineers, 1998). By removing particulates and associated nutrients and contaminants from the water column and redistributing them to the sediments, zebra mussels affect water quality, nutrient and contaminant cycling, and sediment quality (US Army Corps of Engineers, 1998). Potential impacts to water quality include degradation of dissolved oxygen resources, increased nutrient cycling (which may impact community structure), increased water clarity, increases in macrophyte communities, changes in benthic communities, and reductions and changes in phytoplankton communities (US Army Corps of Engineers, 1998)

One of the biggest documented impacts to water quality from dense populations of zebra mussels is increased water clarity (Reeders & de Vaate, 1990; MacIsaac, 1996; US Army Corps of Engineers, 1998; US Army Corps of Engineers, 2002; Cummings & Graf, 2009; Benson & Raikow, 2012). The improved water clarity results from the direct and indirect removal of suspended material from the water column. Direct removal of phytoplankton, zooplankton, detritus, and inorganic material from the water column increases water clarity and light penetration. By removing nutrients from the water column to the benthos, phytoplankton levels can be indirectly reduced by a lack of nutrients. With the decrease in phytoplankton and chlorophyll *a* levels in the water column, primary production shifts toward rooted macrophytes as increased water clarity allows macrophyte growth on bottom areas previously limited by light penetration (MacIsaac, 1996; US Army Corps of Engineers, 1998; US Army Corps of Engineers, 2002; Benson & Raikow, 2012). Increased water clarity may shift a lakes trophic classification from eutrophic towards oligotrophic if chlorophyll *a* and nutrient concentrations decrease and Secchi disk depths increase (US Army Corps of Engineers, 1998). The ability of zebra mussels to “beneficially” impact water quality has led to their recommendation and use as a water quality management tool (Reeders & de Vaate, 1990; MacIsaac, 1996; US Army Corps of Engineers, 1998; Dioniso Pires, Bontes, Van Donk, & Ibelings, 2005).

4 ZORINSKY LAKE ZEBRA MUSSELS

4.1 SURVEY OF EMERGED ZEBRA MUSSEL SHELLS

Reconnaissance inspections just prior to and after the winter 2010/2011 winter drawdown of Zorinsky Lake indicated a very low abundance of zebra mussels relative to levels reported in the literature for infested waters. To gain a better understanding of the zebra mussel population that was present in Zorinsky Lake at the time of the 2010/2011 winter drawdown, in was decided to survey the exposed bottom of the reservoir for the occurrence of emerged adult zebra mussel shells.

Preliminary post-drawdown inspections of Zorinsky Lake for zebra mussel shells during the 2010/2011 winter indicated that most of the emerged zebra mussels shells seemingly had detached and were lying on the substratum. If heavy rains occurred before a survey could be completed, the exposed zebra mussel shells likely would be carried to locations remote from where they were attached. This would limit the collection of accurate location data of where live zebra mussels were actually attached. Heavy rainfall would also likely cover emerged zebra mussel shells with debris. Also, as time expired and temperatures warmed, predation and degradation of exposed zebra mussel shells would occur. For these reasons, the survey for zebra mussel shells was conducted as soon as snow and ice conditions allowed for an adequate inspection of the exposed bottom of Zorinsky Lake. The survey for emerged zebra mussel shells was conducted from 24-Feb-2011 to 11-Mar-2011. During the period from when Zorinsky Lake reached full drawdown (4-Jan-11) through completion of the survey for emerged zebra mussel shells (11-Mar-11) no significant rainfall occurred. The location data collected for the emerged zebra mussel shells is believed to accurately identify locations where living zebra mussels were attached.

4.1.1 SURVEY METHODS

Two explanatory variables were identified for the zebra mussel shell survey: 1) substrate, and 2) elevation. Substrates types were identified as hard or soft. Hard substrates were further identified as 1) rock riprap (limestone), 2) gravel, 3) concrete (blocks or rubble), 4) other – to be specified. Soft substrates (i.e., soil) were surveyed less extensively. Since Zorinsky Lake experiences significant seasonal thermal stratification and hypoxia, elevation was identified as an indicator of water quality affects. Priority areas identified for early inspection were riprap and concrete substrates through as great an elevation range as possible.

The emerged area of Zorinsky Lake between the elevation 1110 and 1093 ft-NGVD29 was delineated into inspection areas (Plate 39). Inspection areas were prioritized to help ensure a representative survey of available substrate types and elevations was conducted as soon as possible to avoid concerns of disturbance and movement of exposed zebra mussel shells. Given the indication from the preliminary inspections of a very low occurrence of zebra mussels in Zorinsky Lake, it was decided to inspect a significant portion of all "hard" substrates emerged by the drawdown of the reservoir.

4.1.1.1 Inspection of Emerged Reservoir Bottom

Systematic inspections of selected, delineated areas were carried out by a team of individuals consisting of inspectors, recorders, and a team leader. Prior to inspecting an area, the team leader marked the boundaries of the area and the inspectors were briefed, as necessary, on zebra mussel shell identification. In most cases the inspectors were trained biologists. When inspecting an area, inspectors formed a line, in close proximity to each other, walking along the elevation contour and searching for visible zebra mussel shells. Also, selected substrate material (i.e., riprap) was moved to expose any hidden zebra mussel shells below. When a zebra mussel shell was located, the inspector marked the location with a survey flag and continued on. Recorders followed the inspectors and labeled the survey flags with unique collection numbers, logged the information, and collected the zebra mussel shell. To reduce the number of survey flags to be surveyed for location, all zebra mussel shells within 1 m^2 could be combined under one survey flag. If combined, the number of zebra mussels shells associated with the survey flag was recorded. The collected zebra mussel shells were placed in sealable plastic bags, labeled, and segregated by the identified inspection areas. The collected zebra mussel shells were transported to the District's water quality field office where they were spread on a flat surface and air dried. Once dried, the segregated zebra mussel shells were stored for later length measurement and growth ring analysis.

4.1.1.2 Surveying Locations of Located Zebra Mussel Shells

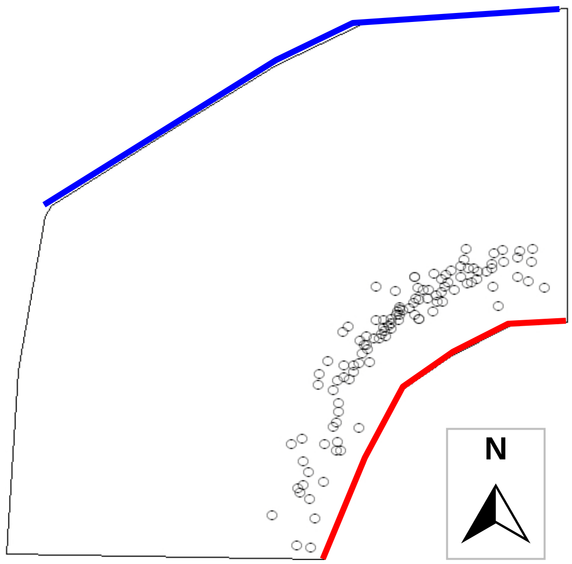
The flagged locations of located zebra mussel shells were surveyed with a GNSS (Global Navigation Satellite System) unit; specifically, a Trimble R8 GNSS VRS Rover. The general accuracies of the Trimble R8 unit used are: ±1 cm horizontally and ±2 cm vertically. Accuracy and reliability are subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The unique identifier on the survey flag was recorded at the time the deployed flags were surveyed for location. Attempts were made to survey the deployed flag locations as soon as possible to avoid the movement of flags before surveying due to vandalism. In all cases, the deployed flags were surveyed the following day and vandalism was not deemed a concern.

4.1.2 SURVEY RESULTS

The emerged areas of Zorinsky Lake that were systematically searched between elevations 1093 and 1110 ft-NGVD29 for the presence of zebra mussel shells included: B1, D1, D4, N6, N10, S4, S7, and W2 (Plate 39). A total of 907 emerged zebra mussel shells were located in the eight searched areas. The location (Northing, Easting, and Elevation) of all located zebra mussel shells were determined and the type of substrate where the zebra mussel was found was identified.

4.1.2.1 Spatial Occurrence

The spatial occurrence of zebra mussel shells found in the eight areas that were systematically searched was plotted aerially and by elevation. Aerial views of the areas searched were constructed using ArcMap (ESRI, 2009). Elevation views of the search areas were constructed by plotting shoreline length on the x-axis and elevation on the y-axis. The locations of found zebra mussel shells in each of the eight search areas are plotted aerially and by elevation in Figure 4-1 through Figure 4-8. The depicted emerged lake bottom areas are based on aerial views and should be considered minimum estimates as the sloping reservoir bottom is not accounted for. The occurrence of the total 907 located shells by elevation is shown in Figure 4-9. Descriptive statistics for the emerged shell location elevations (ft-NGVD29) are: minimum = 1100.3, maximum = 1109.1, median = 1105.1, mean = 1105.2, standard error = 0.04, and standard deviation = 1.24. The elevation locations are normally distributed ($p < 0.01$).



Area B1

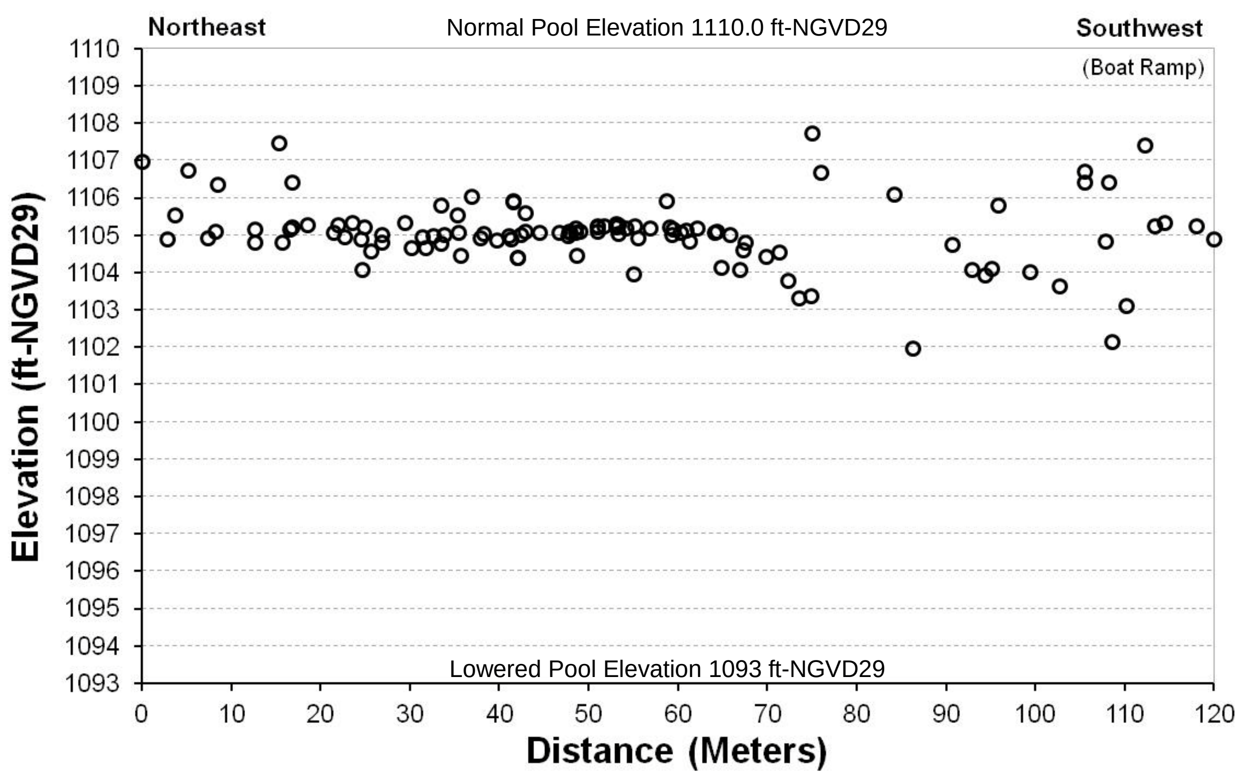
Area B1 Description

Shoreline Length: 100 meters
Emerged Lake Bottom: 8,500 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

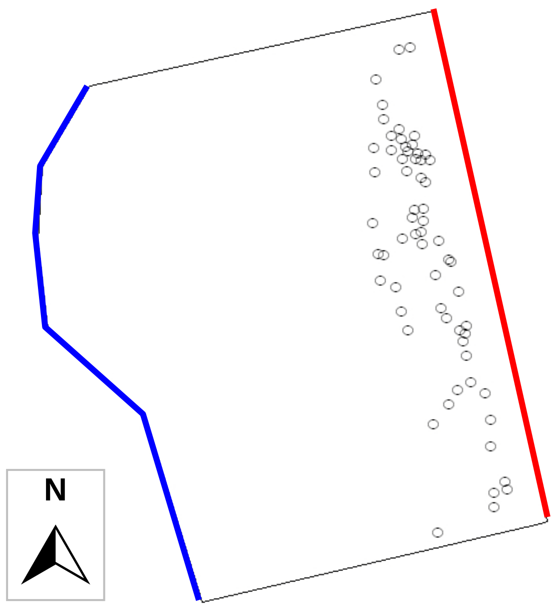
Number of Zebra Mussel Shells Found: 262
Elevations of Shell Occurrence:
  Range: 1102.0 to 1107.8 ft-NGVD29
  Median: 1105.1 ft-NGVD29
Occurrence by Substrate:
  Gravel/Cobble: 65.6%
  Riprap: 29.4%
  Soil: 5.0%

Depicted aerial view of Area B1 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area B1.

Figure 4-1. Description of Area B1 and the locations of found zebra mussel shells.



Area D1

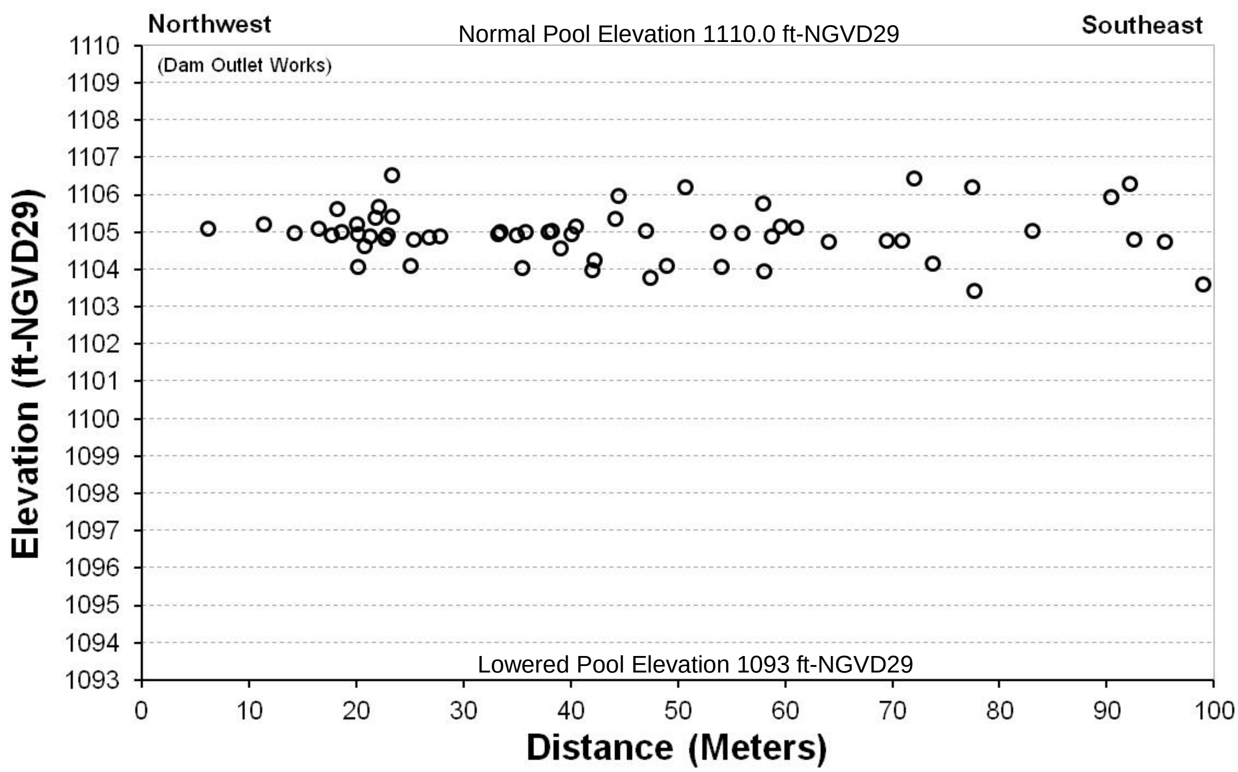
Area D1 Description

Shoreline Length: 100 meters
Emerged Lake Bottom: 7,700 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

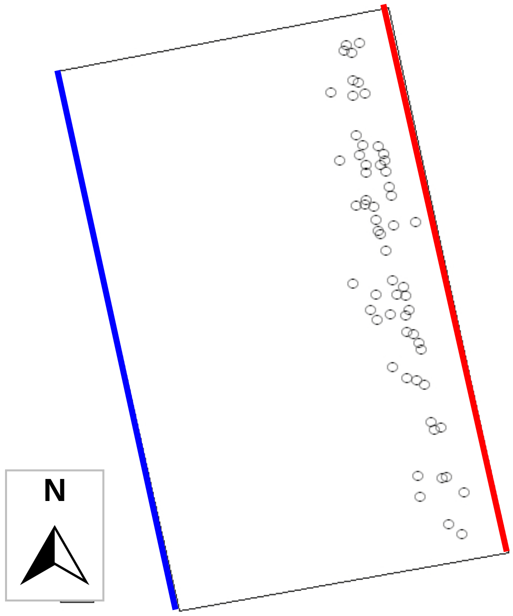
Number of Zebra Mussel Shells Found: 90
Elevations of Shell Occurrence:
Range: 1103.4 to 1106.5 ft-NGVD29
Median: 1105.0 ft-NGVD29
Occurrence by Substrate:
Gravel/Cobble: 68.9%
Riprap: 30.0%
Soil: 1.1%

Depicted aerial view of Area D1 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area D1.

Figure 4-2. Description of Area D1 and the locations of found zebra mussel shells.



Area D4

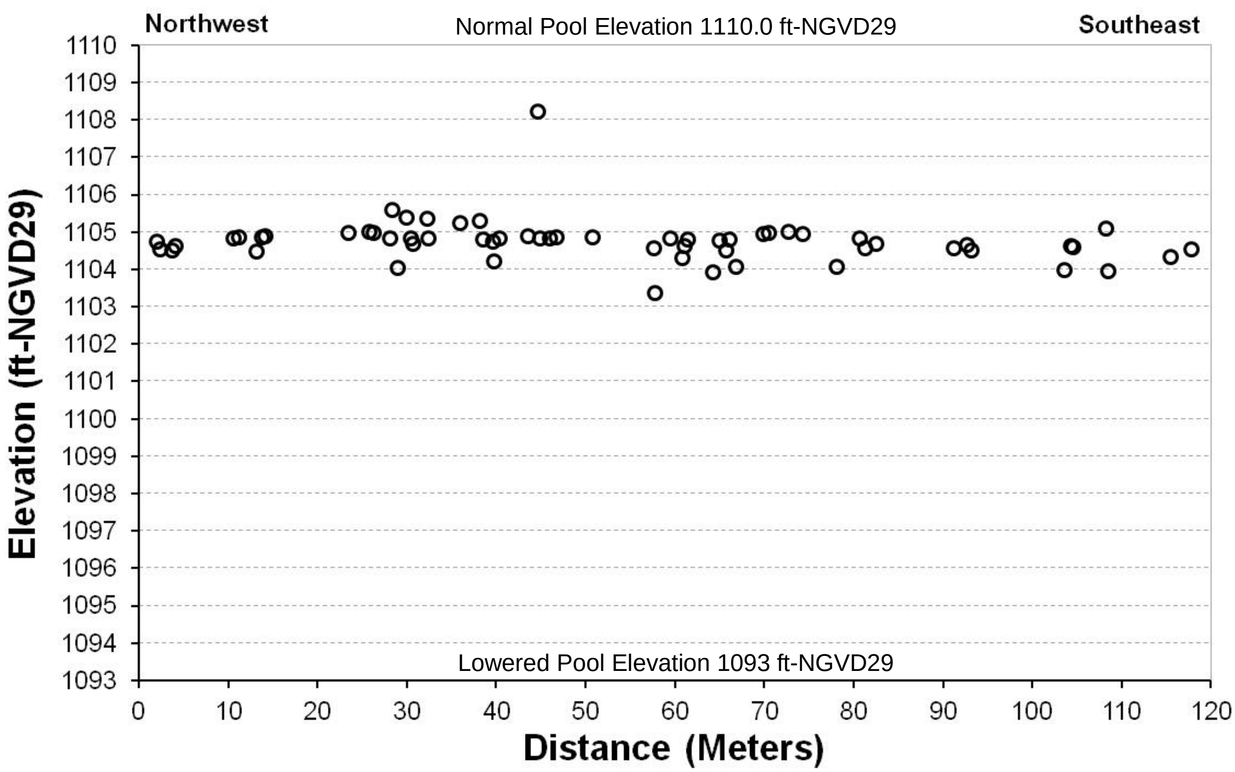
<u>Area D4 Description</u>

Shoreline Length: 120 meters
Emerged Lake Bottom: 8,700 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

<u>Zebra Mussel Shells</u>

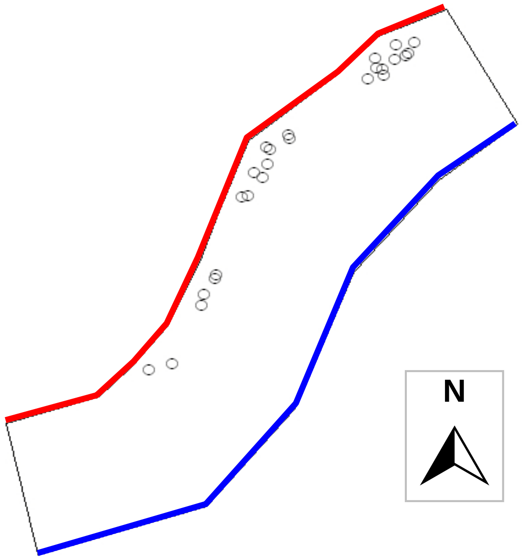
Number of Zebra Mussel Shells Found: 147
Elevations of Shell Occurrence:
    Range: 1103.4 to 1108.2 ft-NGVD29
    Median: 1104.8 ft-NGVD29
Occurrence by Substrate:
    Gravel/Cobble: 86.4%
    Riprap: 12.9%
    Tire: 0.7%

Depicted aerial view of Area D4 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area D4.

Figure 4-3. Description of Area D4 and the locations of found zebra mussel shells.



Area N6

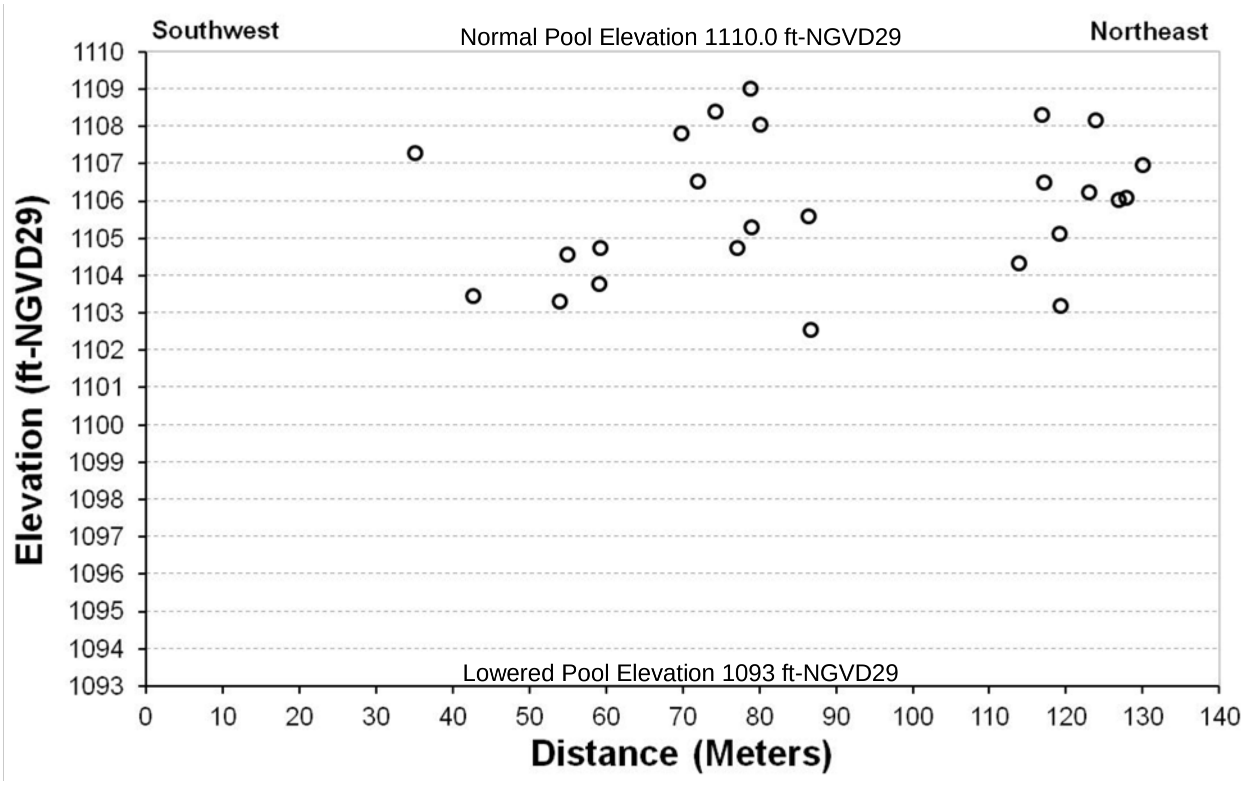
Area N6 Description

Shoreline Length: 140 meters
Emerged Lake Bottom: 4,500 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

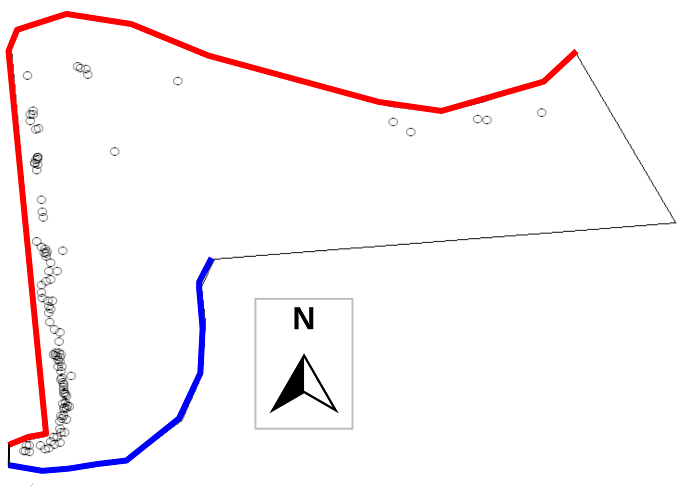
Number of Zebra Mussel Shells Found: 26
Elevations of Shell Occurrence:
Range: 1102.6 to 1109.0 ft-NGVD29
Median: 1105.8 ft-NGVD29
Occurrence by Substrate:
Riprap: 96.2%
Tire: 3.8%

Depicted aerial view of Area N6 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area N6.

Figure 4-4. Description of Area D4 and the locations of found zebra mussel shells.



Area N10

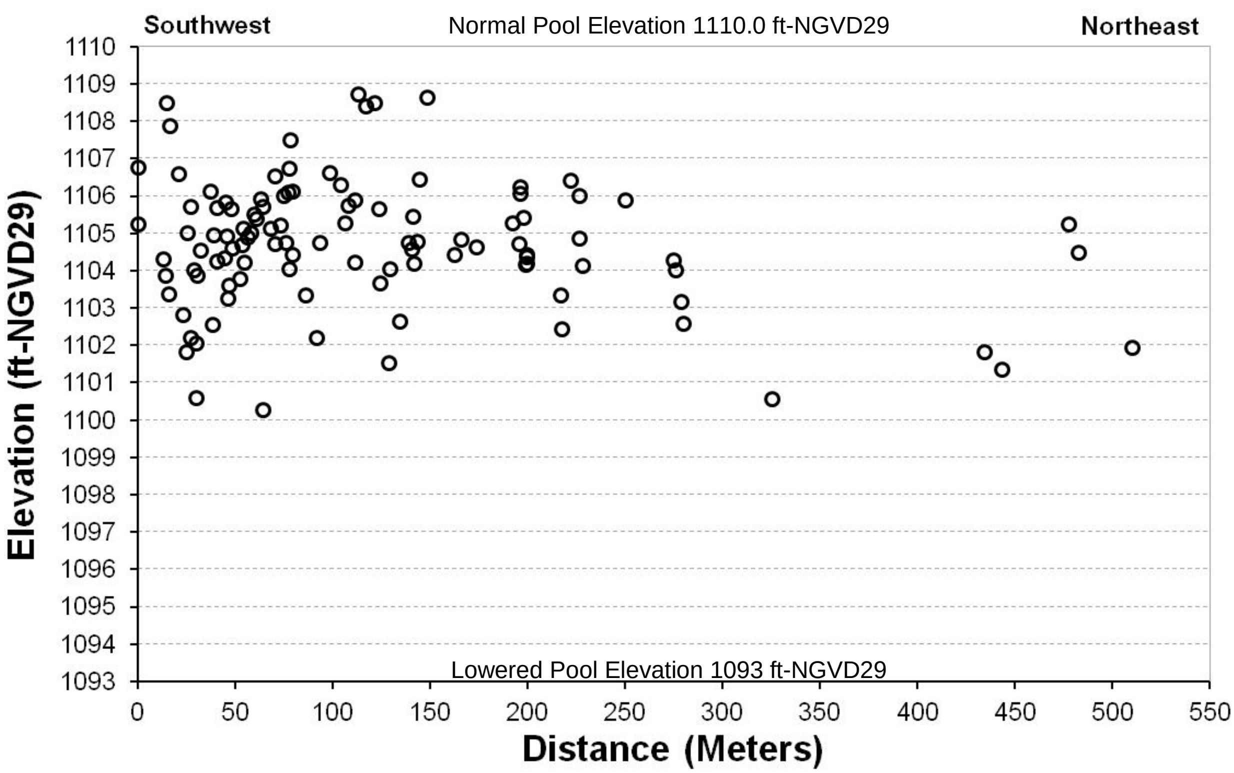
Area N10 Description

Shoreline Length: 550 meters
Emerged Lake Bottom: 37,300 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

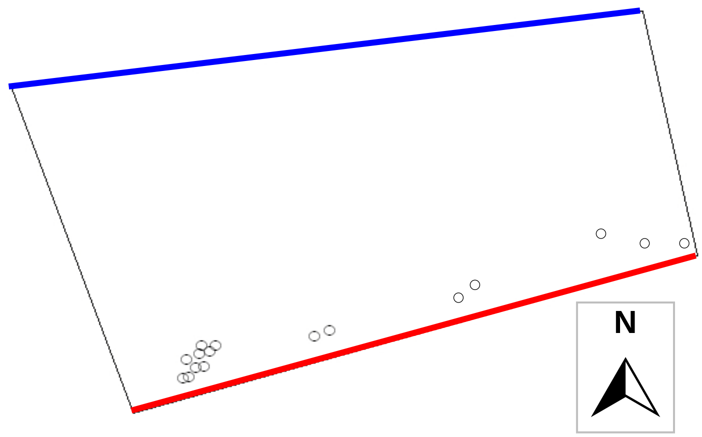
Number of Zebra Mussel Shells Found: 171
Elevations of Shell Occurrence:
  Range: 1100.3 to 1108.7 ft-NGVD29
  Median: 1104.8 ft-NGVD29
Occurrence by Substrate:
  Bottle: 0.6%
  Concrete: 0.6%
  Gravel/Cobble: 0.6%
  Riprap: 95.9%
  Soil: 1.8%
  Woody Debris: 0.6%

Depicted aerial view of Area N10 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area N10.

Figure 4-5. Description of Area N10 and the locations of found zebra mussel shells.



Area S4

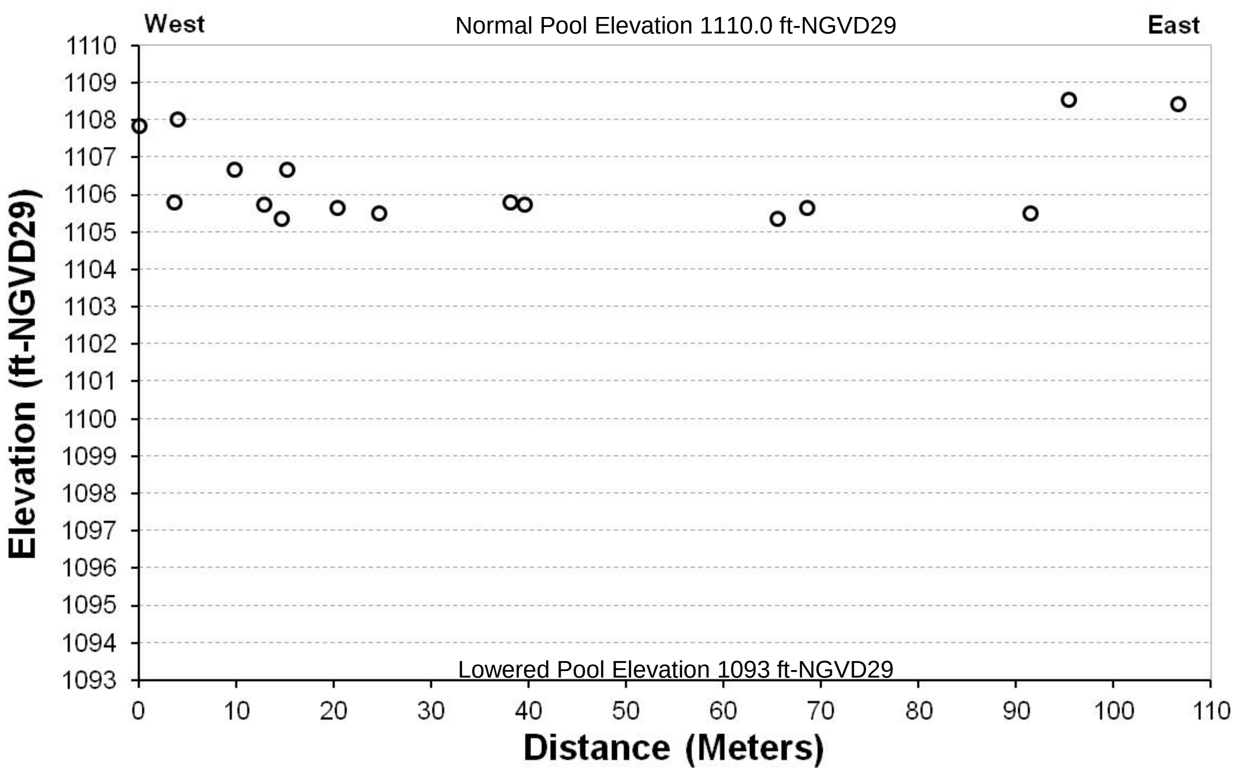
Area N10 Description

Shoreline Length: 110 meters
Emerged Lake Bottom: 6,000 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

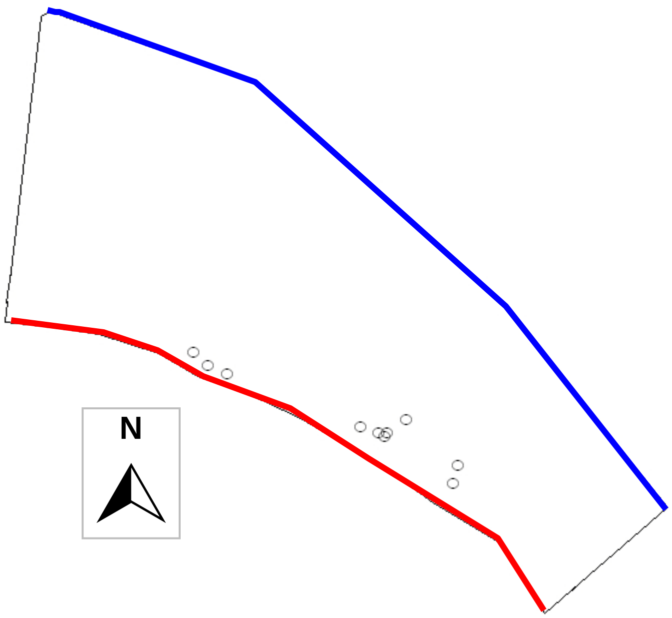
Number of Zebra Mussel Shells Found: 17
Elevations of Shell Occurrence:
  Range: 1105.4 to 1108.6 ft-NGVD29
  Median: 1105.8 ft-NGVD29
Occurrence by Substrate:
  Gravel/Cobble: 41.2%
  Riprap: 58.8%

Depicted aerial view of Area S4 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area S4.

Figure 4-6. Description of Area S4 and the locations of found zebra mussel shells.



Area S7

Area N10 Description

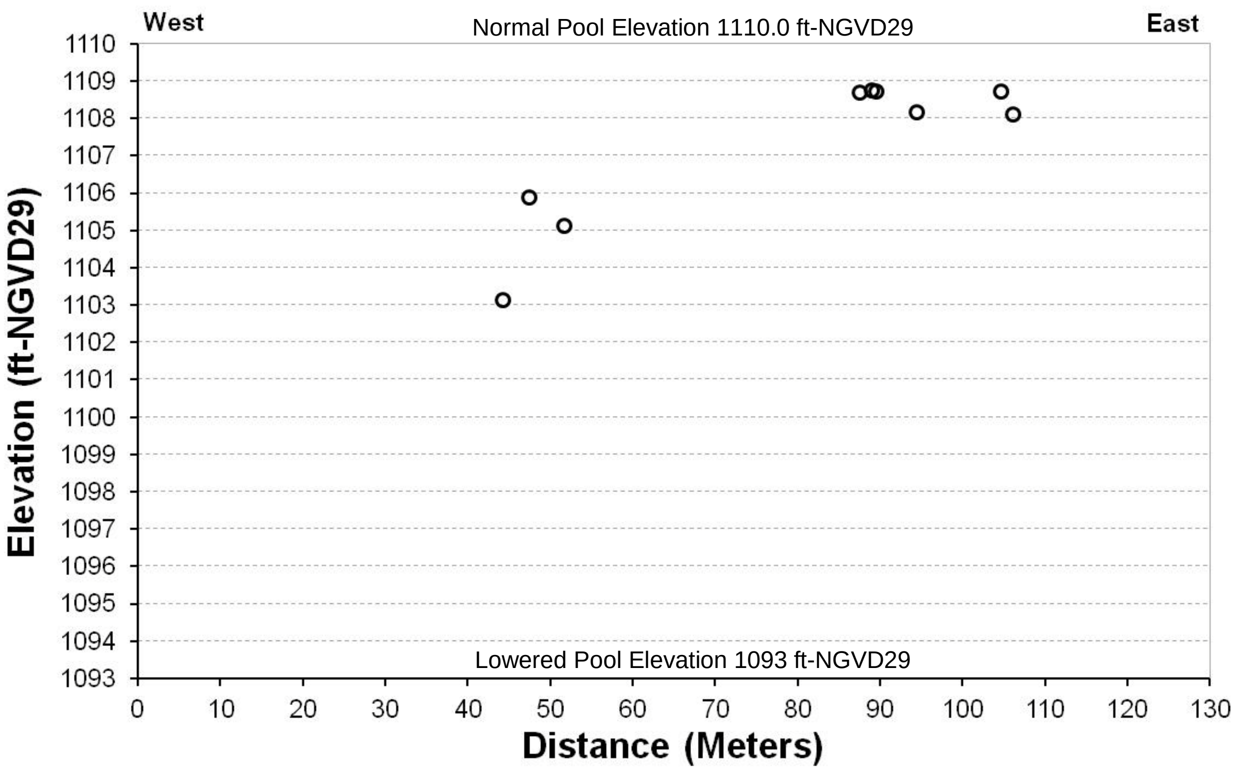
Shoreline Length: 130 meters
Emerged Lake Bottom: 7,300 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

Number of Zebra Mussel Shells Found: 11
Elevations of Shell Occurrence:
- Range: 1103.2 to 1108.8 ft-NGVD29
- Median: 1108.2 ft-NGVD29

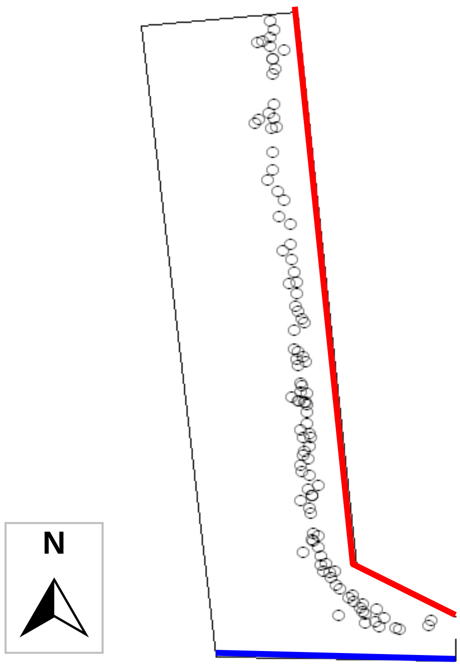
Occurrence by Substrate:
- Gravel/Cobble: 27.3%
- Riprap: 72.7%

Depicted aerial view of Area S7 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area S7.

Figure 4-7. Description of Area S7 and the locations of found zebra mussel shells.



Area W2

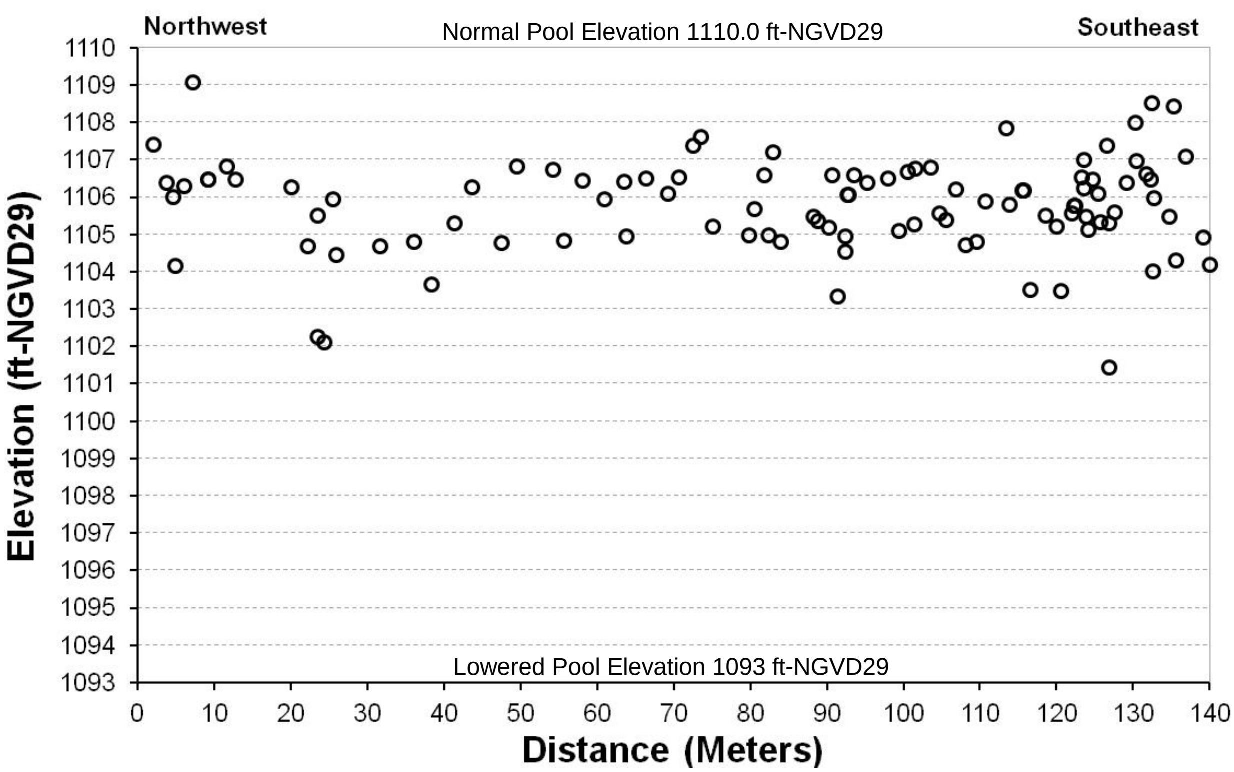
Area N10 Description

Shoreline Length: 140 meters
Emerged Lake Bottom: 4,300 m^2
Elevation Range: 1110 to 1093 ft-NGVD29

Zebra Mussel Shells

Number of Zebra Mussel Shells Found: 183
Elevations of Shell Occurrence:
Range: 1101.4 to 1109.1 ft-NGVD29
Median: 1106.0 ft-NGVD29
Occurrence by Substrate:
Riprap: 98.4%
Soil: 1.6%

Depicted aerial view of Area W2 showing the locations of found zebra mussel shells. *(Red line indicates normal pool shoreline – elevation 1110 ft-NGVD29. Blue line indicates the lake edge at lowered pool level – elevation 1093 ft-NGVD29.)*



Elevation depiction of the locations of found zebra mussel shells in Area W2.

Figure 4-8. Description of Area W2 and the locations of found zebra mussel shells.

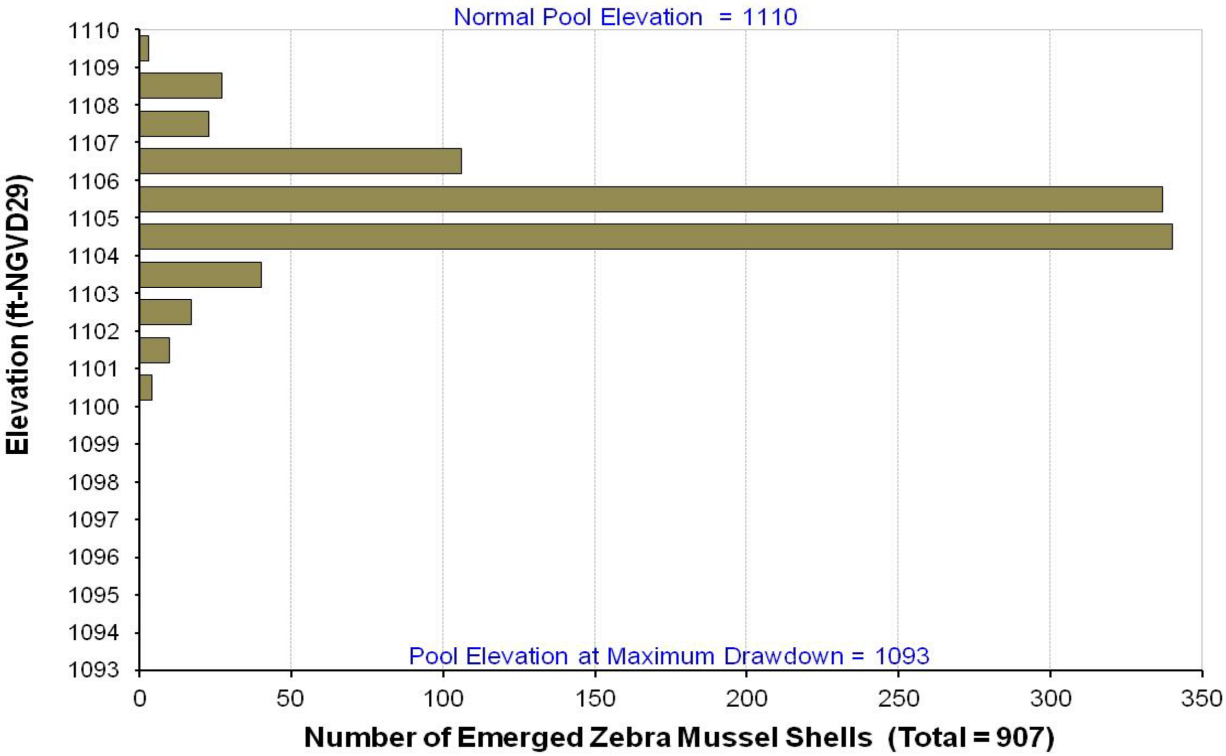


Figure 4-9. Occurrence of the 907 emerged zebra mussel shells located in Zorinsky Lake by elevation.

4.1.2.2 <u>Substrate Occurrence</u>

Emerged zebra mussel shells were found associated with seven types of substrates: 1) bottle, 2) concrete, 3) gravel/cobble, 4) riprap, 5) soil, 6) tire, and 7) woody debris. Figure 4-1 through Figure 4-8 give the percent occurrence of emerged zebra mussel shells with each substrate type for each of the eight areas surveyed. The percent occurrence, by substrate, for all 907 emerged zebra mussel shells located was: riprap, 56.2%; gravel/cobble, 40.9%; soil, 2.2%; tire, 0.2%; bottle, 0.1%; concrete, 0.1%; and wood, 0.2%.

Extensive areas of formerly submerged "tree stumps", tires, and concrete blocks, were emerged with the drawdown of Zorinsky Lake. The tires and concrete blocks were previously installed on the bottom of Zorinsky Lake for fish habitat. Also, a former road bridge with concrete and steel debris was emerged with the drawdown of Zorinsky Lake. In almost all cases these substrates occurred below elevation 1100 ft-NGVD29 and no zebra mussel shells were found associated with them. The few cases where emerged zebra mussel shells were found attached or associated with these substrates were at elevations above 1100 ft-NGVD29.

4.1.3 ZEBRA MUSSEL SURVEY DISCUSSION

Based on the survey of emerged shells, the zebra mussel population at Zorinsky Lake when the reservoir was drawn down in December 2010 was sparse and widespread. Zebra mussels were present in all areas of the reservoir with suitable substratum above elevation 1100 ft-NGVD29. Where present, zebra mussel average densities were well less than 1 mussel per m^2, and only approached 1 mussel per m^2 in some areas where they were most abundant. This compares to reported densities of 5,000-30,000

mussels per m^2 which commonly occur during problem infestations. The sparse, widespread zebra mussel population indicated by the collection of emerged zebra mussel shells suggests a population that was being limited by environmental factors present in Zorinsky Lake.

A recent invasion of zebra mussels in Zorinsky Lake would likely have been characterized by a point of introduction (e.g., boat ramp area, etc.) with a higher density of mussels in that area, and the population radiating outward along dispersion paths. This was not the case at Zorinsky Lake as indicated by the emerged zebra mussel shell survey. Zebra mussels were ubiquitously present in Zorinsky Lake on hard substrates above elevation 1100 ft-NGVD29, both upstream and downstream of the 168th Street embankment. The embankment poses a limited restriction to the movement of water and the passive dispersal of zebra mussel veligers. A possible explanation could be that zebra mussels were initially introduced to Zorinsky Lake upstream of 168th Street, and then veligers passively moved downstream to the rest of reservoir. If veligers were initially introduced downstream of 168th Street their passive colonization upstream of 168th Street would have taken some time unless they were subsequently transported above 168th Street through human intervention. Even with human intervention it is unlikely that the sparse, widespread zebra mussel population indicated throughout Zorinsky Lake is representative of a recent introduction. A more plausible explanation is that zebra mussels have been present in Zorinsky Lake for an extended period, and time has allowed for their spread throughout the reservoir.

The occurrence of zebra mussels in Zorinsky Lake was centered on elevation 1105 ft-NGVD29. No emerged shells were found below 1100 ft-NGVD29 and few emerged shells were found above 1109 ft-NGVD29. Poor water quality is believed to have limited the zebra mussel population in Zorinsky Lake to elevations above 1100 ft-NGVD29. Zorinsky Lake thermally stratifies and hypoxic conditions regularly extend from the reservoir bottom to elevation 1100 ft-NGVD29 during the summer. This is the period when most of the more oxygen-sensitive zebra mussel veligers would be expected to settle, and it would appear that settlement below elevation 1100 ft-NGVD29 was not survivable. Settlement could occur later in the year when hypoxia had dissipated, but hypoxia during winter and the following summer would extirpate these mussels. Low pH levels that occur in the lower depths of Zorinsky Lake during thermal stratification also likely limited veliger survival. Wave action, ice scour, and sunlight avoidance, among other things, are likely to have limited zebra mussel occurrence above elevation 1109 ft-NGVD29.

Other water quality conditions that could be part of the reason for the low abundance of zebra mussels in Zorinsky Lake are water temperature and suspended solids levels. Water temperatures commonly approach 30°C in the epilimnion of Zorinsky Lake during the summer. Water temperatures this warm interfere with zebra mussel spawning and the survival of veligers. Zorinsky Lake regularly experiences high suspended solids and siltation as pulses of runoff carry suspended material through the reservoir. High suspended solids levels interfere with zebra mussel feeding and cause physiologic stress. Pulses of high suspended solids and turbidity during the summer would also be detrimental to survival of planktonic veligers.

The vast majority of emerged zebra mussel shells were collected from areas of hard substratum. This is as expected given the preference of zebra mussels for hard substratum. The majority of the substratum present in Zorinsky Lake is mud/silt. Hard substratum in the reservoir is primarily associated with riprap that has been placed along the dam, the 168th Street embankment, and selected areas for shoreline erosion control. Hard substratum exists below elevation 1100 ft-NGVD29, but was not used by zebra mussels due to poor water quality.

Zebra mussel occurrence in Zorinsky Lake was limited to elevations above 1100 ft-NGVD29, presumably due to hypoxic water quality conditions. Zebra mussel occurrence above elevation 1100 ft-NGVD29 was limited to the relatively few areas of hard substratum. Within these areas, other water quality factors (temperature, suspended solids, and siltation) likely limited zebra mussel survival.

4.2 ASSESSMENT OF COLLECTED ZEBRA MUSSEL SHELLS

The collected zebra mussel shells were assessed to estimate their age. The shells were aged to provide further insights into the Zorinsky Lake zebra mussel population. Two methods were used to age the collected shells and the represented zebra mussel population: 1) size-frequency analysis and 2) growth ring analysis.

4.2.1 SIZE-FREQUENCY OF COLLECTED SHELLS

4.2.1.1 Size-Frequency Methods

Size-frequency distributions have been used in numerous age and growth studies of zebra mussels (Akcakaya & Baker, 1998; Karatayev, Burlakova, & Padilla, 2006; Strayer & Malcom, 2006). They are most revealing in populations that have highly synchronized spawning and settlement and low inter-individual variation in growth. In these cases, newly settled mussels form a distinct size cohort and these cohorts give a distinct size structure to the population (Karatayev, Burlakova, & Padilla, 2006). In water bodies where zebra mussels continually spawn and produce veligers throughout the summer, a wide size range of individuals (up to 16 mm) can result by the end of the first growing season. In these cases, settled veligers will not form distinct annual size cohorts and a distinct size structure will not be seen in the population (Karatayev, Burlakova, & Padilla, 2006).

4.2.1.1.1 Measurement of Shell Size

The size (i.e., lengths) of the collected emerged zebra mussel shells were measured from the umbo to the farthest posterior edge with a digital caliper and recorded to nearest millimeter (mm). In most cases, the two shell halves of a single adult were still attached and only one of the shell halves was measured. When only one of the shell halves was collected it was measured. The measured shell lengths were entered into a spreadsheet and segregated by the identified collection areas. The largest zebra mussel shell collected at Zorinsky Lake measured 44 mm.

4.2.1.1.2 Cohort Identification based on Shell Size

The shell size data were used to construct a frequency histogram. Cursory examination of the histogram indicated distinct size cohorts were present. To analyze the shell size data for size cohorts, the data were assessed with FiSAT II. FiSAT II is a Microsoft Windows based program package supported by the Food and Agriculture Organization of the United Nations mainly for the analysis of fish population length-frequency data (Gayanilo, Sparre, & Pauly, 2005).

4.2.1.2 Size-Frequency Results

A total of 797 she1ls were measured out of the 907 that were located during the Zorinsky Lake zebra mussel survey. The 110 shells which were not measured were either damaged or given away as reference specimens for public education. A distribution plot of the sizes of the measured zebra mussel shells is shown in Figure 4-10. The zebra mussel shell size data indicate the presence of two distinct size cohorts. These size cohorts are identified as cohorts 1 and 2 in Figure 4-10. Size cohort 0 is believed to be young-of-the-year zebra mussels that settled in 2010. The assumed small size (i.e., < ~11 mm) and camouflaging of young-of-the-year zebra mussels made finding their shells very difficult during the survey for emerged zebra mussel shells. It was concluded that the survey was bias in this regard and under-represented young-of-the-year zebra mussels. It is believed that young-of-the-year zebra mussels are represented by the few larger individuals as indicated in length cohort 0 and possibly by a few individuals in the lower end of identified cohort 1. Size cohort 3 is believed to be represented by a few

larger individuals likely in the final stages of senescence. Cohort 1 identifies the second size cohort and has an average length of 16.1 mm and a standard deviation of 2.3 mm. Cohort 2 identifies the third size cohort and has an average length of 28.7 mm and a standard deviation of 3.6 mm. Cohort 3 identifies the last size cohort and has an average length of 39.0 mm and a standard deviation of 2.6 mm.

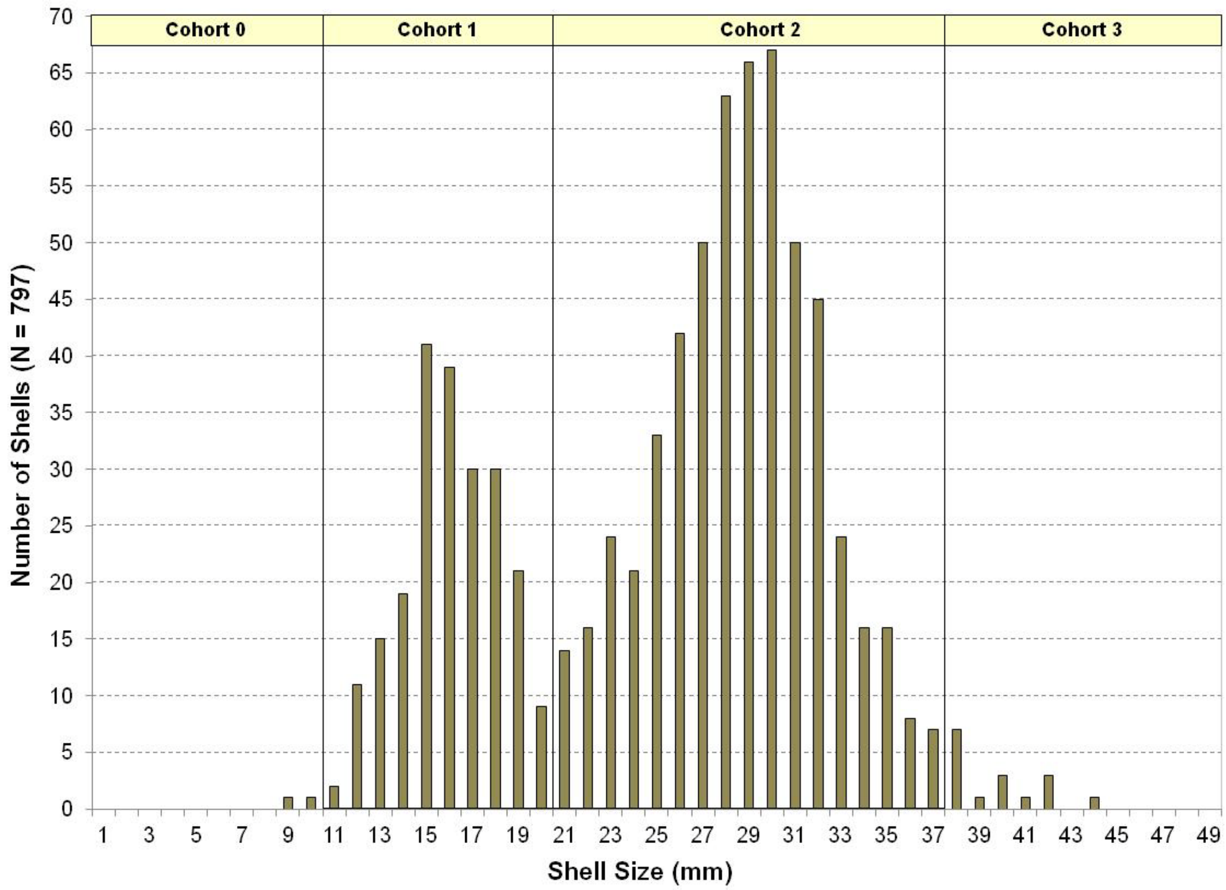


Figure 4-10. Distribution of the lengths of the 797 emerged zebra mussel shells that were measured. (The four size cohorts believed to be present are identified.)

FiSAT II was used to statistically assess the Zorinsky Lake zebra mussel shell size data for size cohorts using modal progression analysis (MPA). MPA refers to a methodology that infers growth from the apparent shift of the modes or means in a time series of size-frequency data. MPA involves three stages: 1) decomposition of composite distributions into their components to identify means, 2) subjective identification and "linking" of the means perceived to belong to the same cohorts, and 3) using the growth increments and size-at-age (relative) data resulting from the linking to estimate growth parameters. In FiSAT II, two methods are provided to analyze composite size-frequency distributions: 1) Bhattacharya's method (Bhattacharya, 1967) and 2) NORMSEP. NORMSEP applies the maximum likelihood concept to SEParation of the NORMally distributed components of size-frequency samples (Hasselblad, 1966). The results from the Bhattacharya's method utility were used as input to the NORMSEP program in FiSAT II to assess the zebra mussel shell size data. Output from the NORMSEP program's assessment of the shell size data is shown Figure 4-11. Size cohorts 1, 2, and 3 are identified and the separation indices (S.I.) are above 2, which indicate that the separation is reliable (Gayanilo, Sparre, & Pauly, 2005). The three size cohorts also conform to the rule that distinct modes or cohorts can only be observed if the difference

between the means is greater than twice the standard deviation of the mode with the larger spread (Gayanilo, Sparre, & Pauly, 2005). Size cohort 3 is not well observed in the distribution plot of the emerged zebra mussel shells (Figure 4-10); however, this cohort is identified by the MPS analysis.

Results ---------

Group	Mean	s.d.	Population	S.I.
1	16.09	2.337	228	n.a.
2	28.66	3.621	558	4.222
3	39.01	2.621	16	3.315

Plot ---------------

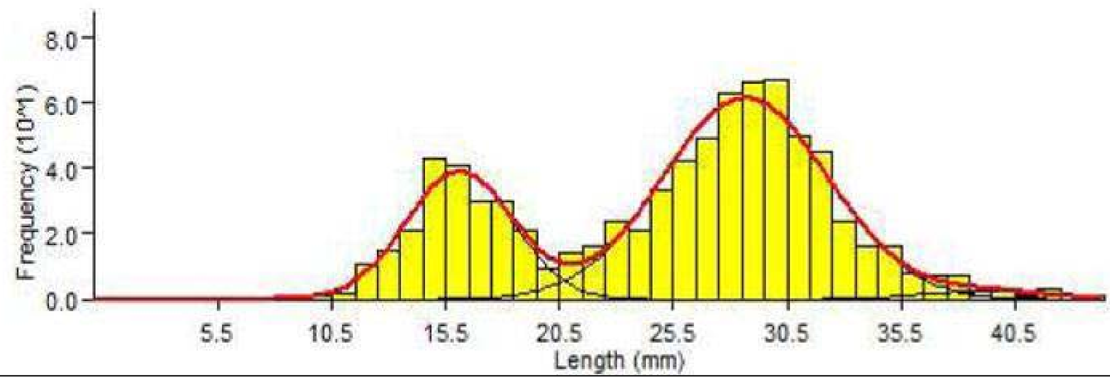


Figure 4-11. Output from the NORMSEP program run on the Zorinsky Lake zebra mussel shell sizes.

Cohort analysis results from the FiSat II program were confirmed using the software package Rmix (Du,2002). Rmix has been successfully used to estimate zebra mussel cohort size in previous studies (Strayer & Malcom, 2006). Analysis were done using 1-mm-wide shell classes and one to three cohorts. Results were consistent with those obtained from the FiSat II program.

4.2.2 GROWTH RING ASSESSMENT OF COLLECTED SHELLS

Many bivalves exhibit pronounced bands, rings, or ridges on the exterior surface of their shells (Lewandowski, 1983; Cummings & Graf, 2009). The distance between rings progressively decreases as they approach the posterior edge of the shell (Cummings & Graf, 2009). These rings are formed as a result of slowed growth and are referred to as winter growth bands, slowed growth bands, annular rings, annuli, or growth rings (Cummings & Graf, 2009). Zebra mussel growth annually slows during the winter, but slow growth can also occur during spawning and in response to stressing environmental factors (Lewandowski, 1983; Karatayev, Burlakova, & Padilla, 2006; Cummings & Graf, 2009). In eutrophic lakes, both winter and summer annuli can be formed if environmental conditions slow growth (Lewandowski, 1983).

One of the oldest and most common methods for estimating the age and growth of zebra mussels is by counting annual rings on shells and comparing it to shell size (Stanczykowska, 1963; Karatayev, Burlakova, & Padilla, 2006). However, counting growth rings is very subjective as it is difficult to distinguish annual rings from rings formed because of other factors that slow growth (Bij de Vaate, 1991;

Karatayev, Burlakova, & Padilla, 2006). Small zebra mussels that settled at the end of the growing season do not produce a first annual ring, and these mussels can be incorrectly identified as young-of-the-year of the following year (Karatayev, Burlakova, & Padilla, 2006).

4.2.2.1 Growth Ring Methods

4.2.2.1.1 Identification of Collected Shell Growth Rings

A subsample of 20 shells was randomly taken from each surveyed area except S4 and S7. In areas S4 (n = 17) and S7 (n = 9) all undamaged shells were used. This resulted in a total of 146 shells being selected for measurement. All shells were segregated by collection area and kept in separate containers. Accumulated organic material was removed from the shell exterior using a soft nylon brush and damp cheesecloth. Two shells were discarded due to damage incurred removing organic material (i.e., N = 144). Growth rings were then identified visually and with the aid of a dissecting microscope. All identification and measurement was performed by the same individual in order to minimize variation due to measurement error. Following removal of organic material the banding coloration was still obscured on the exterior of most shells. However, shells had growth rings which were so pronounced they could be identified by the raised thickening of the shell edge. Once identified, growth rings were viewed under the dissecting microscope and marked with a small dot of white paint along the dorsal shell edge. Growth rings were counted and the distance between growth rings was measured as the distance from the umbo to the marked growth ring along the dorsal shell edge. All distance measurements were taken using digital calipers and recorded to the nearest 0.1 mm.

4.2.2.2 Assessment of Growth Rings

All growth ring data were entered into a spreadsheet for analysis (i.e., number of growth rings, total shell size, growth ring size, and survey area). The number of growth rings was used to place the shells into age classes. Descriptive statistics were determined for each age-class. The sizes of the determined age-classes were compared to the sizes of the size-cohorts determined from the size-frequency analysis.

4.2.2.3 Growth Ring Results

4.2.2.3.1 Age-Class Determination

Six age classes (0 to 5) were determined based on the observed occurrence of growth rings in the assessed shells. Table 4-1 summarizes the age determination and growth ring measurements for the 144 assessed zebra mussel shells. An analysis of variance (ANOVA) was conducted to assess differences in shell size between age classes. Shell sizes were found to be significantly different between age classes ($p < 0.001$). Of the shells assessed the vast majority were in age classes 1 through 4 (n=132) (Figure 4-12).

Based on age-class determination, zebra mussels at Lake Zorinsky could seemingly grow up to 16 mm in their first year followed by a decline to 12.6 and 10.4 mm, respectively, in their second and third years. However, determining age class 0 and age class 1 is problematic as late settling veligers typically do not form an annuli their first year (Karatayev, Burlakova, & Padilla, 2006). As such, the larger mussels identified as age class 0 may actually be age class 1 individuals from the previous fall. A growth rate of 16 mm the first year would indicate fast growing zebra mussels, and it's likely the determined age class 0 includes some age class 1 individuals.

Table 4-1. Age-class determination and growth ring measurements for assessed zebra mussel shells.

Determined Age Class	No. of Shells Assessed	Observed Growth Rings	Distance from Umbo (mm) Mean	Minimum	25th Percentile	Median	75th Percentile	Maximum
0	2	Shell	10.8	9.6	10.2	10.8	11.4	12.0
1	35	Shell	13.8	10.8	12.7	13.9	15.0	17.3
		Ring 1	10.4	8.7	9.6	10.2	11.2	12.3
2	29	Shell	19.4	15.2	17.0	18.9	20.9	26.0
		Ring 1	10.6	6.4	9.8	10.5	11.0	16.2
		Ring 2	15.8	10.9	14.4	15.6	16.9	21.4
3	35	Shell	26.3	19.6	23.3	26.5	28.6	34.1
		Ring 1	11.1	8.0	9.9	11.1	12.0	14.1
		Ring 2	16.8	12.5	15.5	16.5	18.3	23.0
		Ring3	22.3	17.5	20.5	22.2	23.9	28.1
4	33	Shell	30.4	23.2	29.2	30.6	32.5	36.4
		Ring 1	11.1	8.3	10.0	10.8	12.6	14.5
		Ring 2	17.1	12.5	15.7	17.3	18.8	22.5
		Ring 3	21.9	16.2	19.9	22.5	23.7	27.8
		Ring 4	26.8	20.6	24.7	26.8	28.5	32.1
5	10	Shell	36.7	27.3	34.6	36.8	40.3	42.4
		Ring 1	10.9	9.1	10.0	10.8	11.7	13.1
		Ring 2	17.1	13.3	15.6	17.6	18.4	21.1
		Ring 3	22.5	17.8	20.3	22.1	24.3	29.1
		Ring 4	27.4	20.4	24.9	27.7	29.3	35.0
		Ring 5	32.2	23.9	30.1	33.3	34.7	38.4
Combined Data from above Age Classes (0 – 5)	144	Shell	23.3	9.6	16.2	23.3	29.5	42.4
		Ring 1	10.8	6.4	9.8	10.6	11.8	16.2
		Ring 2	16.6	10.9	15.0	16.5	18.2	23.0
		Ring 3	22.1	16.2	20.3	22.4	24.0	29.1
		Ring 4	26.8	20.4	24.5	26.7	29.1	35.0
		Ring 5	32.2	23.9	30.1	33.3	34.7	38.4

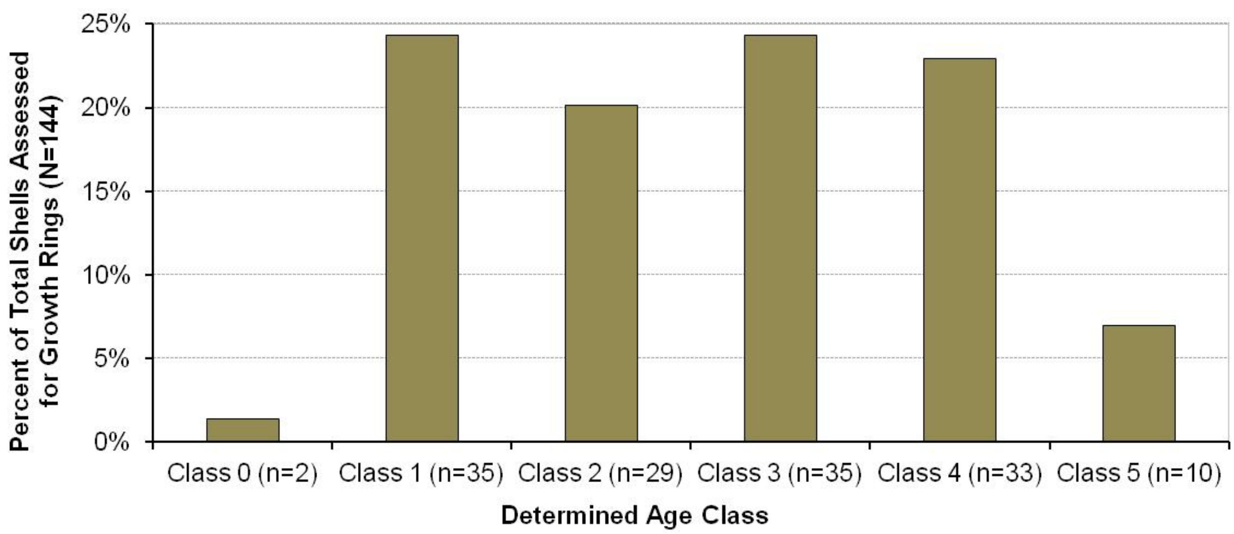


Figure 4-12. Distribution of the zebra mussel shell size and determined age classes.

4.2.2.3.2 Comparison of Age Classes, Size Cohorts, and Shell Size

The interquartile range of the six determined age classes were overlaid on the size-frequency histogram and the size cohorts determined from the 797 measured emerged zebra mussel shells (Figure 4-13). The "interquartile" ranges for age class 0 and 5 are open-ended; representation of the 25th percentile for age class 0 and the 75th percentile for age class 5 are omitted as these groups are considered inclusive of the youngest and oldest members of the population. The upper quartile limit of age class 0 (11.4 mm) correlates with upper limit of length cohort 0 (10 mm). The lower limit of the age class 1 interquartile range (12.7 mm) and the upper limit of the age class 2 interquartile range (20.9 mm) correlate with the range of size cohort 1 shells (10 mm to 20 mm). The lower limit of the age class 3 interquartile range (23.3 mm) and the upper limit of the age class 4 interquartile range (32.5 mm) correlate with range of size cohort 2 shells (size 20 mm to 38mm). The lower quartile limit of age class 5 (34.6 mm) correlates with the lower limit of size cohort 3 (38 mm).

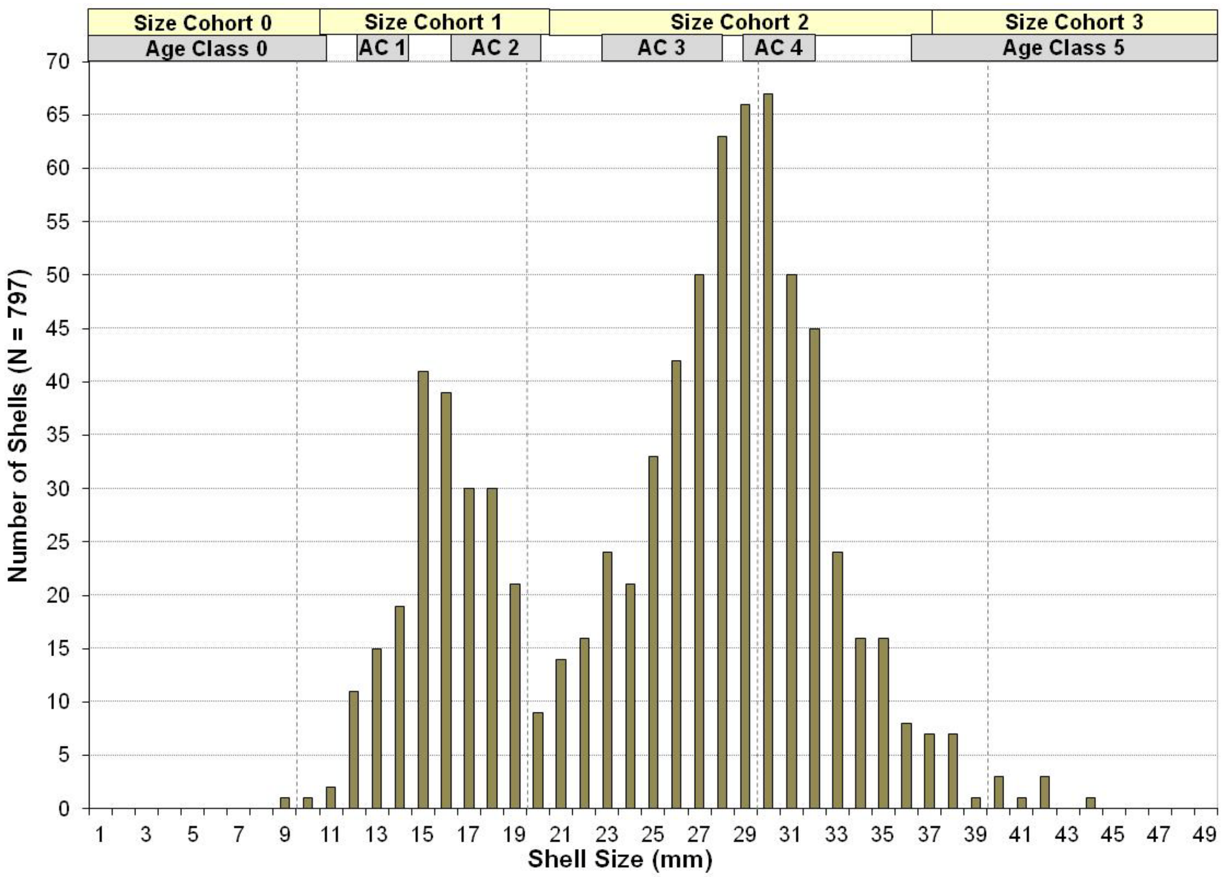


Figure 4-13. Comparison of the growth ring determined age class interquartile lengths to the length frequency histogram based on the total 797 emerged zebra mussel shells measured.

The observation of two growth rings (i.e. age classes) within a single size cohort is attributed to growth inhibition during the summer in addition to the regular growth inhibition during the winter. Zebra mussels show growth inhibition during spawning and when water temperatures reach levels near or above 28°C (Aldridge, Payne, & Miller, 1995; Cummings & Graf, 2009). Both of these occur during the summer at Zorinsky Lake and likely cause growth inhibition. This would result in two growth rings being formed within one calendar year; winter and summer. The formation of two annuli by zebra mussels has been documented in eutrophic lakes, such as Zorinsky Lake, due to adverse environmental conditions during the summer (Lewandowski, 1983).

4.2.3 SHELL ASSESSMENT DISCUSSION

The size cohorts and age classes determined from the emerged zebra mussel shells collected at Zorinsky Lake indicate the presence of four year classes (Figure 4-14). Shell size at the ends of year classes overlap as early settlers of a previous year class can show more growth than late settlers of the following year class. Also, "micro-niches" with differing environmental conditions can result in inter-individual growth variation and increase the "noise" in zebra mussel sizes at year class boundaries. In general, young-of-the-year zebra mussels are believed to be represented by age class 0 and size cohort 0 and make up the 2010 year class (Figure 4-14). The 2010 year class is under represented due to sampling bias associated with the difficulty in locating small emerged zebra mussel shells characteristic of young-of-the-year. Age class 1 and 2 and size cohort 1 are believed to represent the 2009 year class (Figure 4-14). Age class 3 and 4 and size cohort 2 are believed to represent the 2008 year class (Figure 4-14). Age class 5 and size cohort 3 are believed to represent the 2007 year class which was comprised of a few larger individuals in the final stages of senescence (Figure 4-14). The "dips" in the number of shells between year classes is due to the extended time period between spawning. Growth and veliger production cease during winter. In early spring and late fall growth occurs and no veligers are produced, resulting in a period of shell size increases but no new individuals recruited to the population. The distinct annual cohorts and size structure of the population indicated by the size-frequency assessment of the emerged shells indicates that zebra mussel spawning in Zorinsky Lake may have been synchronized over a short period. The low density of the zebra mussel population in Zorinsky Lake seemingly reduced the probability of released eggs and sperm coming together to form a fertilized egg. Synchronization of spawning over a shorter time period would likely have increased the probability of released eggs and sperm to form fertilized eggs. This would give the highest potential for veilger production and mussel recruitment to maintain a viable population.

The size-frequency and growth ring assessment of the emerged shells indicate that the largest zebra mussels in Zorinsky Lake were 3+ years old when the reservoir was drawn down in December 2010. It has been reported that adult (i.e., sexually mature) zebra mussels range from approximately 6 to 45 mm and generally live to be 3+ years old in temperate climates (Akcakaya & Baker, 1998; US Army Corps of Engineers, 2002). This would indicate that the age and growth of the zebra mussels that were emerged when Zorinsky Lake was drawn down were typical of a population in a eutrophic lake in a temperate climate.

4.3 ASSESSMENT OF ZEBRA MUSSEL REFUGIA AREAS

A concern was expressed by the ZLZMT that refugia areas for zebra mussel survival could be provided by the areas still submerged after the winter 2010/2011 drawdown of Zorinsky Lake. To address this concern a survey was conducted of shallow submerged areas in Box Elder Creek upstream of the drawn down pool and immediately downstream of the dam discharge.

4.3.1 ASSESSMENT METHODS

Upstream areas inspected included Box Elder Creek at the 192nd, 180th, and 168th Street bridge crossings, and the flowing water inflow to the lowered Zorinsky Lake pool downstream of 168th Street (Figure 2-1). The downstream area inspected included Box Elder Creek immediately downstream of the dam through the east end of the culvert under 156th Street, a distance of about 100 meters. A small sub-impoundment (D-38) on the north side of Zorinsky Lake just east of 168th Street was also inspected (Figure 2-2). In all areas hard substrates were thoroughly inspected for the presence of attached adult zebra mussels.

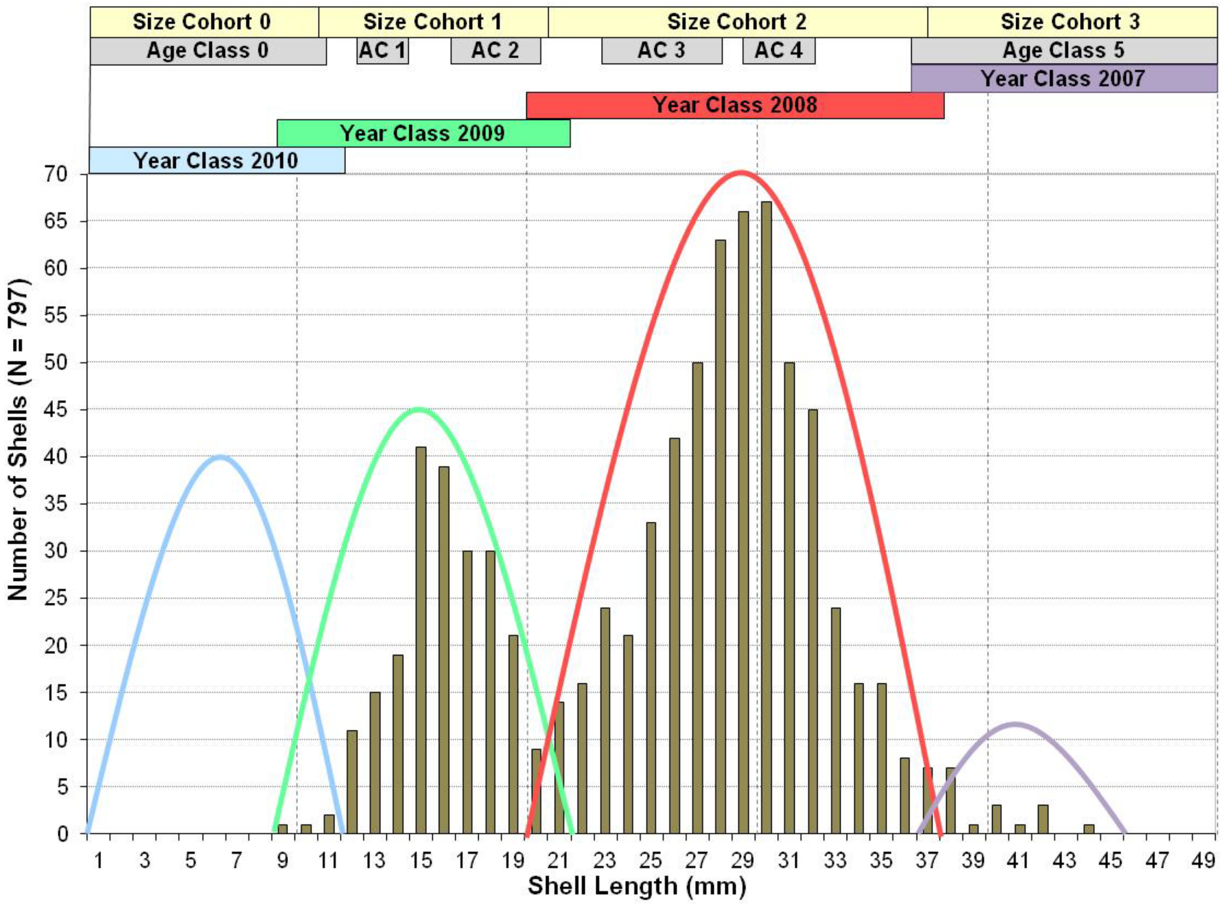


Figure 4-14. Zebra mussel year classes believed to be indicated by the emerged shells collected at Zorinsky Lake in March 2011 after the winter drawdown of the reservoir.

4.3.2 ASSESSMENT RESULTS

The following areas were inspected for live adult zebra mussels on 17-March-2011: 1) Box Elder Creek – 192nd Street bridge crossing, 2) Box Elder Creek – 180th Street bridge crossing, 3) Box Elder Creek – from Zorinsky Dam outlet to 156th Street, 4) D-38 Sub-Impoundment, and 5) Zorinsky Lake – 168th Street bridge crossing.

4.3.2.1 Box Elder Creek – 192nd Street Bridge Crossing

Box Elder Creek at the 192nd Street bridge crossing was flowing water at about 5 cfs. Limestone and concrete rubble were present under the bridge span. Approximately 40 pieces of rubble in the 5 to 50 cm size range were inspected for attached zebra mussels – no zebra mussels were found. Macroinvertebrates found at the site included leeches, chironomids, trichoptera, ephemeroptera, and simulids.

4.3.2.2 Box Elder Creek – 180 Street Bridge Crossing

Box Elder Creek at the 180th Street bridge crossing was ponded. The channel was silt laden and no riprap or rubble was present. The North bridge abutment was in the water and the concrete face was inspected for attached zebra mussels – no zebra mussels were found.

4.3.2.3 Box Elder Creek – from Zorinsky Dam outlet to 156th Street

Box Elder Creek downstream of the Zorinsky Dam outlet was flowing water at about 5 cfs. The rock "drop structure", rock riprap at the approach to the 156th Street culvert, and 156th Street concrete culvert were inspected for attached zebra mussels. Approximately 100 pieces of limestone cobble in the 5 to 50 cm size range were inspected for attached zebra mussels – no zebra mussels were found. Macroinvertebrates were fairly abundant and included unionid clams, gastropods, leeches, trichoptera, ephemeroptera, and chironomids.

4.3.2.4 D-38 Sub-Impoundment

The impounded water above the D-38 dam and the emerged channel downstream of the D-38 dam were inspected. The D-38 sub-impoundment had a dense stand of cattails around most of the perimeter. A small area of riprap existed near the outlet pipe. Approximately 20 pieces of limestone cobble up to 50 cm were inspected for attached zebra mussels – no zebra mussels were found. The submerged 8-inch PVC outlet pipe was inspected to a depth of about ½-meter. The pipe was inspected visually and by running a hand underneath – no attached zebra mussels were found. The emerged channel downstream of the D-38 dam was inspected for dead adult zebra mussels – none were found; however, there were a lot of dead native clams.

4.3.2.5 Zorinsky Lake – 168th Street Bridge Crossing

Box Elder Creek at the 168th Street bridge crossing was flowing water at about 5 cfs. The creek was emerged at the site with the drawdown of Zorinsky Lake. Approximately 20 meters upstream of the bridge the creek was braided through the mud flats of the emerged basin of Zorinsky Lake west of 168th Street. There was significant sheet, rill, and channel erosion occurring through the exposed mud flats as numerous "mini-channels" were being cut and a main channel was becoming established. This resulted in a significant deposition of silty-sediment in the flowing creek channel immediately upstream and downstream of the 168th Street bridge. In the "steeper" section of the channel directly under the 168th Street bridge faster water velocities allowed an area to be "flushed" and sediment deposition was less. Three transects across the existing channel at 168th Street bridge were surveyed to get the bottom elevation of the "wetted" channel on 17-March-2011. The three transects were located: 1) 10-meters upstream of the west side of the bridge, 2) under the middle of the bridge, and 3) 10-meters downstream of the east side of the bridge

Figure 4-15 depicts the bottom elevation of the three transects and the water surface elevation at was present. The wetted channel, as measured at the three transects, was entirely below elevation 1100 ft-NGVD29.

The wetted area of Zorinsky Lake from about 10 meters west to 30 meters east of the 168th Street bridge was inspected for attached zebra mussels. Over 400 pieces of submerged, miscellaneous hard material was inspected. Most of the material inspected was limestone cobble in the 5 to 50 cm size range; however, other metal, plastic, and concrete objects were inspected – no zebra mussels were found. The only live macroinvertebrates found were a few blood worms (i.e., chironmids). The area was essentially a "dead zone" for aquatic life. The wetted area inspected on 17-March-2011 was totally within an area that monitoring indicated was hypoxic to anoxic during the previous summer. The lack of macroinvertebrates likely indicates that the area hadn't had time to re-colonize and recover from the low dissolved oxygen conditions experienced the previous summer. It is highly unlikely that this area provided a refugia for zebra mussel survival during the 2010/2011 winter.

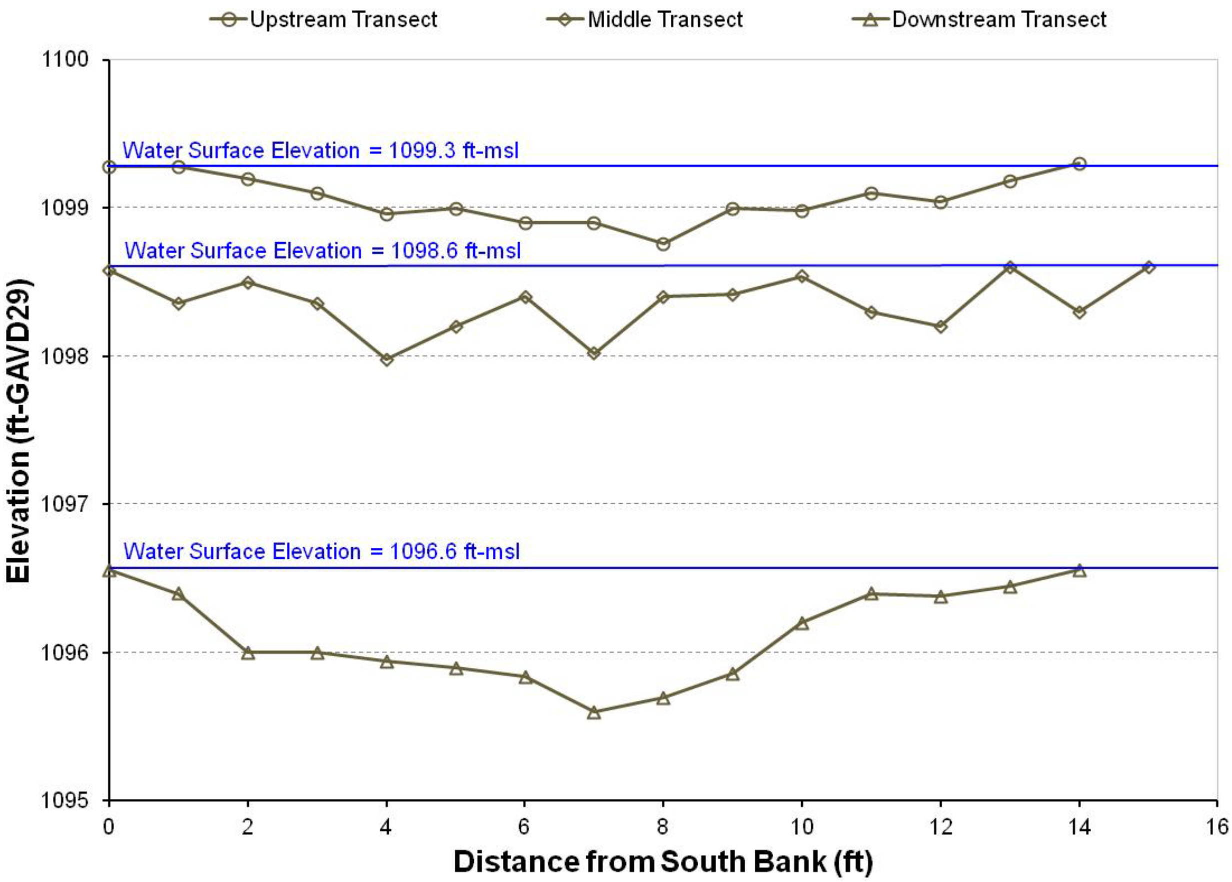


Figure 4-15. Channel bottom and water surface elevations surveyed on Box Elder Creek at the 168th Street bridge crossing on 17-March-2011.

4.4 ZORINSKY LAKE FISH POPULATION PRIOR TO RESERVOIR DRAWDOWN

As was discussed in Section 3.4.3.2, fish predation on zebra mussels has been documented for several species. Fish stocking and survey records for Zorinsky Lake were reviewed to identify the fish species that were present in Zorinsky Lake.

4.4.1 STOCKING RECORDS

The historical stocking records for Zorinsky Lake were obtained from the Nebraska Game and Parks Commission (Nerbaska Game and Parks Commission, 2012). The fish and crayfish that have been stocked into Zorinsky Lake since 1992 are listed in Table 4-2. As mentioned in Section 3.4.3.2, crayfish are a known predator of zebra mussels.

Table 4-2. Aquatic species stocked into Zorinsky Lake by the Nebraska Game and Parks Commission from 1992 through 2010

Fish Species	Date	Number	Size (in)
Blue Catfish	7/21/1992	11,710	7 - 9
	8/14/2002	7,620	10
	7/27/2006	3,338	11
	8/23/2007	7,650	9
Channel Catfish	8/24/1993	5,100	6 - 8
	9/19/1994	5,100	9
	9/12/1996	5,100	9 - 10
	9/17/1998	5,000	9
	8/31/2000	7,350	10
	9/8/2004	7,650	8
	8/31/2005	6,080	10
	9/13/2005	1,000	10
	8/15/2006	4,300	10
	9/3/2008	3,825	10
	9/4/2008	3,825	10
	9/16/2008	6,880	10
	9/1/2009	7,660	9
	9/15/2010	7,650	10
Largemouth Bass	7/9/2008	16,860	1.5
	10/21/2008	12,898	4
	4/19/2009	79	15
Muskellunge	3/27/2007	200	13
	4/29/2008	180	12
Striped Bass Hybrid (Wiper)	9/29/2009	2,650	5
	9/23/2010	2,580	5
Tiger Muskellunge	9/9/1993	2,637	10
	9/7/1995	2,550	11
Walleye	10/2/2002	3,800	8
	9/16/2003	3,818	7
	8/12/2004	2,540	5
	9/18/2006	3,675	8
	6/11/2008	25,500	1.5
	6/10/2009	38,000	1.4
	6/8/2010	25,500	1.5
Other Species	**Date**	**Number**	**Size (in)**
Crayfish	7/25/1994	4,875	2

Taken from: Nebraska Game and Parks web site, Fish Stocking Reports page, http://www.outdoornebrasla.ne.gov/fishing/guides/fishguide/FGfindstock.asp

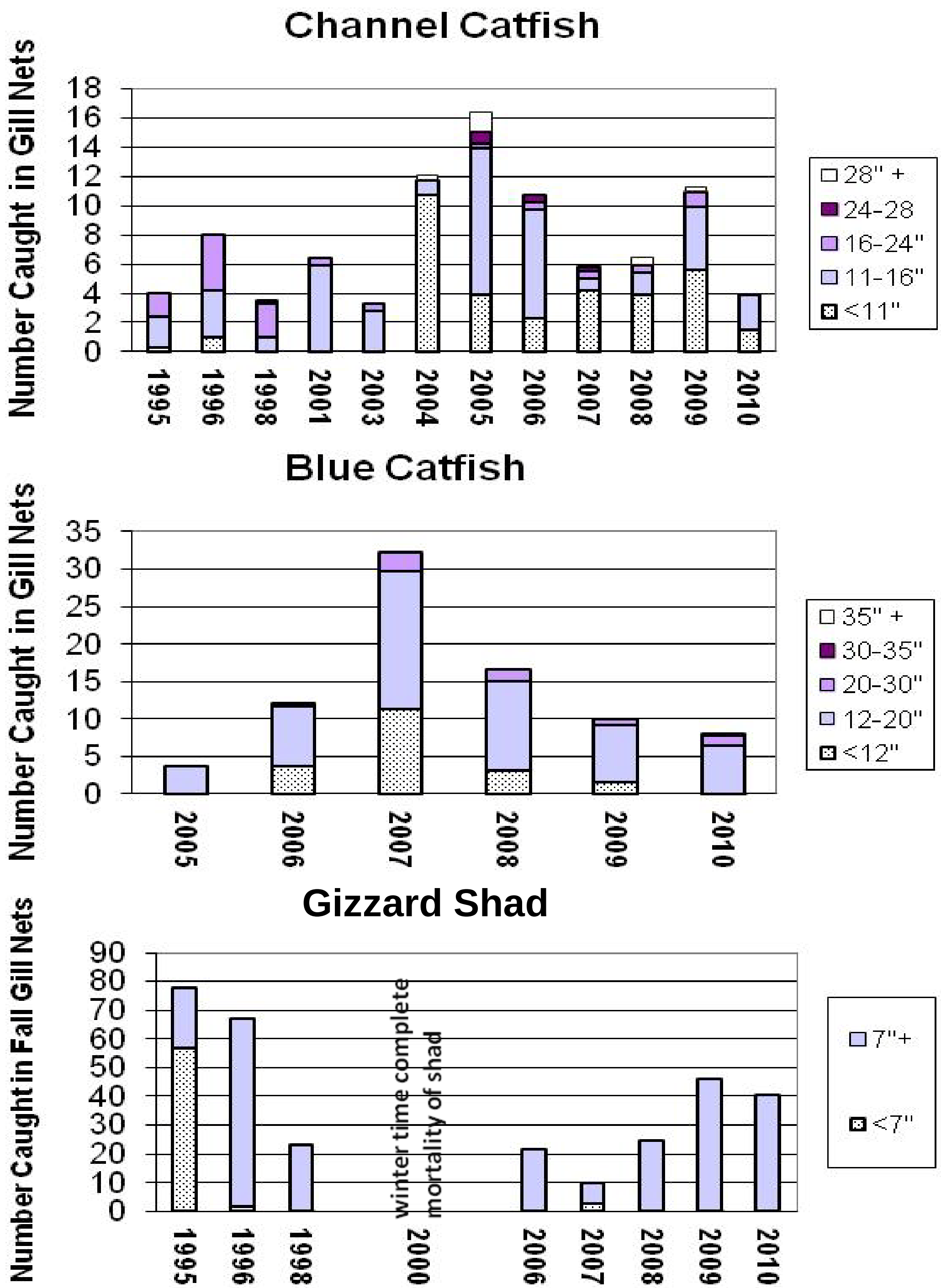
4.4.2 FISH SURVEY RECORDS

Fish collection and survey records for Zorinsky Lake were obtained from the Nebraska Game and Parks Commission (personal communication Jeff Jackson). Relative numbers of channel catfish, blue catfish, gizzard shad, and freshwater drum collected in gill net sampling of Zorinsky Lake are shown in Figure 4-16. The relative numbers of black and white crappie, bluegill, and largemouth bass collected in trap nets are shown in Figure 4-17. Although not indicated in Figure 4-16 and Figure 4-17, common carp were present in Zorinsky Lake. Carp are a ubiquitous species present in most waters throughout the Midwest. Their avoidance of sampling gear makes it difficult to sample them and estimate their population. Although not sampled in significant numbers in Zorinsky Lake, several dead carp were observed during and after the winter 2010/2011 drawdown of Zorinsky Lake and immediately after ice out. Carp were undoubtedly present in Zorinsky Lake, but the extent of their population is not known.

4.4.3 FISH POPULATION DISCUSSION

The fish population of Zorinsky Lake at the time of drawdown contained several species that are known predators of zebra mussels. These species included: blue catfish, freshwater drum, common carp, and bluegill. Crayfish, a know predator of small zebra mussels, was also abundant in Zorinsky Lake. Given the presence of these species in Zorinsky Lake, predation may have played a role in limiting the zebra mussel population in Zorinsky Lake. A possible scenario is that water quality (dissolved oxygen) limited zebra mussels to elevations above 1100 ft-NGVD29. Within this area, zebra mussels were restricted to the few areas of hard substrate. In these areas, water quality conditions (temperature, suspended solids, and turbidity) occasionally stressed zebra mussels and may have lowered their abundance. If the above situations occurred in Zorinsky Lake, predation of zebra mussels of lower abundance in a restricted area may have played a role in limiting the mussel populations.

Given the fecundity of zebra mussels, it is unlikely that predation alone can control their population where environmental conditions are optimal for their growth and reproduction. However, in eutrophic reservoirs where environmental conditions are less than optimal, predation could be factor in limiting zebra mussel populations. Stomach contents of targeted fish species should be sampled to verify fish predation of zebra mussels in any infested District reservoirs.



Freshwater Drum

Figure for freshwater drum not available, the following numbers represent the total average catch rate of freshwater drum per gill net: 2005 = 1.25, 2006 = 2.75, 2009 = 0.75, 2010 =1.75.

Figure 4-16. Catch rate of selected species in gill nets used to sample fish at Zorinsky Lake. (Figures and data provided by the Nebraska Game and Parks Commission, personal communication, Jeff Jackson.)

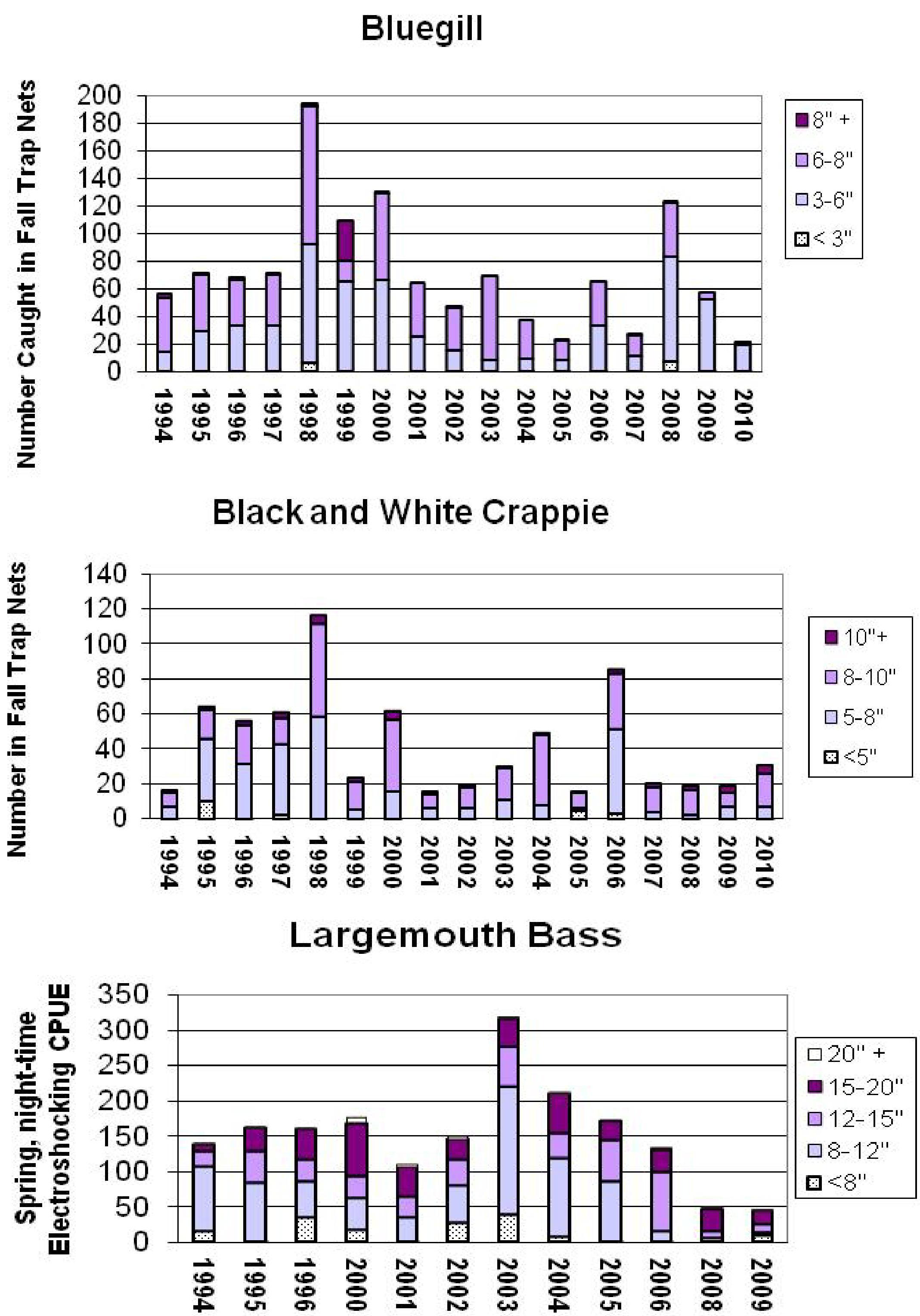


Figure 4-17. Catch rate of selected species in trap nets and by electro-shocking used to sample fish at Zorinsky Lake. (Figures and data provided by the Nebraska Game and Parks Commission, personal communication, Jeff Jackson.)

4.5 EVALUATION OF POSSIBLE ZORINSKY LAKE ZEBRA MUSSEL POPULATION DEMOGRAPHICS

The five possible long-term trajectories for an evasive zebra mussel population identified by Strayer and Malcom (2006) were used to assess the possible population demographics of the Zorinsky Lake zebra mussel population. The identified five long-term population trajectories are: 1) boom-bust, 2) cyclical, 3) equilibrial, 4) irregular, and 5) lag (Figure 3-2). These trajectories were assessed to see if they could account for the observed zebra mussel population indicated by the survey of emerged zebra mussel shells at Zorinsky Lake. The zebra mussel population present in Zorinsky Lake when the reservoir was drawn down had the following characteristics: 1) four year classes of zebra mussels were present, 2) the oldest zebra mussels were 3+ years old, 3) zebra mussels were widespread throughout Zorinsky Lake, 4) zebra mussel density was sparse (<1 mussel per m^2), 5) zebra mussels were not present below elevation 1100 ft-NGVD29 (i.e., 10 feet below the normal pool elevation), and 6) most of the zebra mussels occurred in areas of hard substrate.

The boom-bust cycle is characterized by a high population density lasting a few years after introduction followed by a population crash with low long-term densities. For a boom-bust scenario to apply, given the age structure, density, and distribution of zebra mussels in Zorinsky Lake, the population would need to have been in the "bust phase" at the time the reservoir was drawn down. This would mean the "boom phase" had already occurred. The boom-bust scenario is unlikely as the high population densities associated with the "boom phase" were not observed in the past as would be expected given Zorinsky Lake is a heavily used public resource.

The cyclical population trajectory is characterized by high densities of strong zebra mussel year classes. Given the presence of four year classes, widespread occurrence, and sparse densities of zebra mussels, the cyclic scenario does not fit the zebra mussel population surveyed in Zorinsky Lake.

An equilibrial population trajectory occurs when a population shows a relatively stable density, with the density dependent upon the factors limiting the population. The characteristics of the Zorinsky Lake zebra mussel population conform to an equilibrial scenario. It is probable that environmental conditions including substrate availability, low dissolved oxygen and pH levels below the thermocline, high water temperatures, high levels of inorganic suspended material, siltation, and predation limited the zebra mussel population in Zorinsky Lake.

An irregular population trajectory occurs when there are no long term trends, but large irregular fluctuations in population density occur. Given the population characteristics of the Zorinsky Lake zebra mussel population, the irregular scenario would require that the population was in a "down phase" and that a "peak phase" has not occurred or was not noticed. Although possible, an irregular scenario does not appear likely regarding the observed Zorinsky Lake zebra mussel population.

A lag population trajectory occurs when there is a period of slow growth (a lag phase) which is followed by rapid growth. The characteristics of the Zorinsky Lake zebra mussel population conform to a lag scenario given the uniform density and even distribution of the observed population. It is possible that environmental factors were limiting (i.e., slowing) the growth of the zebra mussel population in Zorinsky Lake. The zebra mussel population could have "exploded" in the future if a limiting factor were removed (e.g., improvement in water quality, addition of riprap for shoreline stabilization or fish habitat, reduced predation, etc). Also, if environmental factors were just slowing the population growth of zebra mussels in Zorinsky Lake, the population density could have reached a "critical mass" at some point in the future which could have allowed the population to "explode".

The population characteristics of the Zorinsky Lake zebra mussel population surveyed when the reservoir was drawn down suggests the population was in an equilibrial or lag long-term trajectory or a combination of both. Multiple environmental factors were likely playing a role in keeping the population density of zebra mussels in Zorinsky Lake from reaching the high levels observed in other infested lakes. In an equilibrial population trajectory it is assumed the factors limiting the population would remain effective and the future population density would remain stable. However, if the limiting factors were only slowing growth or were removed, the population could "explode". Whatever the case, it does seem that the zebra mussel population in Zorinsky Lake would have been space-limited (i.e., small size and substrate availability) and limited by the eutrophic nature of the reservoir.

5 THE ZORINSKY LAKE ZEBRA MUSSEL EXPERIENCE: MANAGEMENT IMPLICATIONS FOR THE DISTRICTS' PAPILLION AND SALT CREEK RESERVOIRS

5.1 CONTROL OF ZEBRA MUSSELS IN ZORINSKY LAKE

The winter 2010/2011 drawdown of Zorinsky Lake is believed to have controlled the zebra mussel population in the reservoir to the maximum extent possible. Water quality conditions at Zorinsky Lake limited the zebra mussel population to areas of the reservoir above elevation 1100 ft-NGVD29. The winter 2010/2011 drawdown of Zorinsky Lake to a pool elevation of 1093 ft-NGVD29 left no wetted areas in the reservoir that supported zebra mussels prior to the drawdown. However, unless adequate controls are put in place, zebra mussels could be reintroduced to Zorinsky Lake as they were in the past. Although 2011 sampling of the other Papillion Creek Reservoirs did not indicate the presence of zebra mussel veligers, the presence of zebra mussels in these reservoirs remains a question. If zebra mussels are present in the other Papillion Creek Reservoirs their reintroduction back into Zorinsky Lake could be facilitated by boat traffic and appropriate management measures should be implemented to address this concern.

5.2 ENVIRONMENTAL CONDITIONS AS LIMITING FACTORS TO THE ESTABLISHMENT OF PROBLEMATIC ZEBRA MUSSEL POPULATIONS IN THE PAPILLION AND SALT CREEK RESERVOIRS

5.2.1 INSIGHTS FROM THE ZORINSKY LAKE EXPERIENCE

Examination of water quality and emerged zebra mussel shell data collected at Zorinsky Lake indicates environmental factors likely played a significant role in keeping the zebra mussel population density low and limited to elevations above 1100 ft-NGVD29. Water quality data for Zorinsky lake indicate that during mid- to late-summer when thermal stratification is at its peak, dissolved oxygen and pH levels below the thermocline (about elevation 1100 ft-NGVD29) were commonly below levels suitable for the survival of zebra mussels. During periods of significant runoff, influent water is commonly laden with particulate matter; a heavy inflow event in June 2008 resulted in turbidity levels above 3000 NTUs in parts of Zorinsky Lake. High turbidity and suspended solids levels can interfere with zebra mussel filter feeding and respiration. High turbidity and suspended solids likely impact the survival of planktonic veligers. Sediment deposition associated with settling of high inorganic suspended solids levels could potentially smother recently settled juvenile zebra mussels. Fine silt deposition on hard substratum can also limit the settling success of veligers and impact juvenile development. The scarcity of suitable hard substrate at Zorinsky Lake likely played a significant role in limiting the zebra mussel population.

A possible scenario at Zorinsky Lake was that water quality conditions (dissolved oxygen and pH) limited zebra mussels to elevations above 1100 ft-NGVD29. Within this area, zebra mussels were restricted to areas of hard substrate. In these areas, water quality conditions (temperature, suspended solids, and turbidity) occasionally stressed zebra mussels and may have lowered their abundance. Predation of zebra mussels in these restricted areas may have played a role in limiting the mussel population. The combination of these limiting factors may account for the widespread but sparse zebra mussel population surveyed in Zorinsky Lake after it was drawn down.

5.2.2 ENVIRONMENTAL CONDITIONS AS LIMITING FACTORS IN THE PAPILLION AND SALT CREEK RESERVOIRS

In relative terms, Zorinsky Lake had the best water quality conditions of any of the Papillion and Salt Creek Reservoirs. All of the reservoirs are either eutrophic or hypereutrophic. All of the reservoirs experience some thermal stratification and associated hypoxia. The “strength” of the stratification and hypoxia is dependent upon local conditions such as reservoir depth and fetch of the prevailing wind. All the reservoirs experience episodic runoff and high levels of suspended solids and turbidity. Water quality conditions in the other reservoirs likely limit any zebra mussel population similar to the situation at Zorinsky Lake. Extensive water quality data are available for all the Papillion and Salt Creek Reservoirs and can be consulted regarding questions concerning zebra mussels.

All the Papillion and Salt Creek Reservoirs have predominantly mud/silt substratum. The availability of hard substrates is believed to be an environmental factor that would limit zebra mussel populations in these reservoirs should zebra mussels become established. It is noted significant additional riprap has been placed in selected reservoirs (i.e., Glenn Cunningham, Holmes, Olive Creek, Wagon Train, and Yankee Hill) as part of lake rehabilitation projects for construction of breakwater jetties and shoreline stabilization.

5.3 POTENTIAL ZEBRA MUSSEL WATER QUALITY IMPACTS TO THE PAPILLION AND SALT CREEK RESERVOIRS

The Papillion and Salt Creek Reservoirs are eutrophic to hyper-eutrophic, nutrient-rich lakes. Most all of them are listed on the State of Nebraska’s Section 303(d) impaired waters list for impairment of aquatic life due to elevated levels of phosphorus, nitrogen, and chlorophyll *a*. Hypothetically, a dense population of zebra mussels in a Papillion or Salt Creek reservoir could increase water clarity, reduce phytoplankton and water-column nutrients, and enhance the growth of macrophytes. Improved water clarity and water-column nutrient reduction could potentially improve water quality conditions in a Papillion or Salt Creek Reservoir enough to allow Section 303(d) delisting for nutrients. Zebra mussels remove phytoplankton, including cyanobacteria, from the water column. Some studies have indicated that zebra mussels alter water column nutrient ratios to the benefit of toxic forms of cyanobacteria, and selectively excrete ingested toxic cyanobacteria toxins such that cyanotoxin levels can actually increase in low nutrient waters (Vanderploeg, et al., 2001; Raikow, Sarnelle, Wilson, & Hamilton, 2004; Sarnelle, Wilson, Hamilton, Knoll, & Raikow, 2005; Bykova, Laursen, Bostan, Bautisa, & McCarthy, 2006; Juhel, et al., 2006). However, the Papillion and Salt Creek Reservoirs are high nutrient waters with excessive, problematic phytoplankton levels.

Water quality improvements associated with zebra mussels are attributed to dense population that can bio-filter filter significant volumes of water. The Zorinsky Lake experience indicates that populations of zebra mussels, if they become established, in the Papillion and Salt Creek Reservoirs would be limited by environmental conditions and dense populations would likely be precluded. As such, the establishment of zebra mussel populations in the Papillion and Salt Creek Reservoirs would not benefit water quality, but would serve as a “seed source” for their spread to other water bodies. At this time, the detriments associated with zebra mussels are believed to outweigh any water quality benefits and their control should continue to be pursued to the extent possible.

5.4 MONITORING FOR ZEBRA MUSSELS IN THE PAPILLION AND SALT CREEK RESERVOIRS

It is likely that zebra mussel populations, if established, in the Papillion and Salt Creek Reservoirs could be widespread, but sparse. Zebra mussel spawning in these reservoirs would likely be synchronized

to improve veliger production. Veligers are difficult to identify in collected plankton samples. Given these conditions, it may be difficult to detect the probable low levels of veligers in plankton samples given their likely episodic occurrence and the inherent difficulty in their identification. The use of settlement plates in addition to targeted veliger sampling may provide the best monitoring to screen for the presence of zebra mussels in the Papillion and Salt Creek Reservoirs. Settlement plates can be placed in the most likely areas to experience any veliger settlement, and would be in place, barring vandalism, during any episodic zebra mussel spawning and subsequent veliger settlement.

5.5 PARTIAL RESERVOIR DRAWDOWN AS A ZEBRA MUSSEL MANAGEMENT TOOL IN THE PAPILLION AND SALT CREEK RESERVOIRS

All of the Papillion and Salt Creek reservoirs are either eutrophic or hypereutrophic and possess organically-rich sediments. Thermal stratification occurs in many of these reservoirs such that hypoxia develops in the lower depths. This limits the depth to which zebra mussels can survive. At Zorinsky Lake, no mussels were found below elevation 1100 ft-NGDV29 – a depth of 10 feet below the normal pool level. The highest density of zebra mussels in Zorinsky Lake were found at elevation 1105 ft-NGVD29, a depth of 5 feet below the normal pool level. In Zorinsky Lake a partial drawdown to 1100 ft-NGVD29 over the winter would have significantly to completely controlled the zebra mussel population in the reservoir. A drawdown to an elevation between 1105 and 1100 ft-NGVD29 would have significantly reduced the zebra mussel population in the reservoir. A similar partial winter drawdown could be employed at the other Papillion and Salt Creek Reservoirs to control a zebra mussel population should one become established. A concern with a partial winter drawdown of any of the Papillion and Salt Creek Reservoirs is a resultant winter fish kill. The organically-rich sediments at all these reservoirs would place a high sediment-oxygen demand on the drawn down reservoir over the winter. If enough volume did not remain in the reservoir over the winter to assimilate the sediment-oxygen demand a fish kill could occur due to hypoxia. It is assumed that Zorinsky Lake experienced a significant fish kill during the 2010/2011 winter draw down. Water depths at Zorinsky Lake during the winter 2010/2011 drawdown ranged from 6 feet near the dam to 12 feet at mid-lake.

6 RECOMENDATIONS

1) Continue water quality monitoring at Zorinsky Lake to document and assess possible water quality impacts from the 2010/2011 winter drawdown and subsequent refilling of the reservoir.

2) Apply the CE-QUAL-W2 hydrodynamic and water quality model to Zorinsky Lake to evaluate using the low-level outlet for hypolimnetic discharge to enhance the reservoir's water quality and fishery.

3) Investigate the use of hypolimnetic discharge to enhance water quality and fisheries at all the Papillion and Salt Creek Reservoirs.

4) Continue veliger and settlement plate monitoring to assess the occurrence and abundance of zebra mussels in the Districts' Papillion and Salt Creek Tributary Reservoirs.

5) Conduct zebra mussel vulnerability assessments at the Papillion and Salt Creek Reservoirs to identify potential impacts to infrastructure and authorized project purposes.

6) Further assess the potential to control zebra mussels in the Districts' Papillion and Salt Creek Reservoirs, should they become established, through modest pool level regulation.

7) Identify and implement measures that can help prevent reintroduction of zebra mussels to Zorinsky Lake.

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8 PLATES

Plate 1. Summary of water quality conditions monitored in Zorinsky Lake at site EZRLKND1 from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for chlorophyll a (lab determined), hardness, metals, microcystin, and pesticides are for "grab samples" collected at a near-surface depth. Results for other parameters are for "grab samples" collected at near-surface and near-bottom depths.]

	Monitoring Results						Water Quality Standards Attainment		
Parameter	**Detection Limit**	**No. of Obs.**	**Mean[A]**	**Median**	**Min.**	**Max.**	**State WQS Criteria[B]**	**No. of WQS Exceedances**	**Percent WQS Exceedance**
Pool Elevation (ft-NGVD29)	0.1	26	1110.7	1110.5	1108.9	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	394	21.7	21.8	12.4	29.4	32[1]	0	0%
Dissolved Oxygen (mg/l)	0.1	394	5.3	5.9	0.1	12.7	≥ 5[2]	104	30%
Dissolved Oxygen (% Sat.)	0.1	372	60.9	70.7	1.0	153.4	-----	-----	-----
Specific Conductance (umho/cm)	1	382	470	494	291	633	2,000[3]	0	0%
pH (S.U.)	0.1	373	7.8	7.9	6.7	8.7	≥6.5 & ≤9.0[1]	0	0%
Turbidity (NTUs)	1	372	38	13	0	3000	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	382	252	258	-136	504	-----	-----	-----
Secchi Depth (in.)	1	25	36	27	12	95	-----	-----	-----
Alkalinity, Total (mg/l)	7	50	134	131	100	170	>20[1]	0	0%
Ammonia, Total (mg/l)	0.02	50	-----	0.1	n.d.	2.7	11.1 [4,5], 1.87 [4,6]	0, 1	0%, 2%
Chlorophyll *a* (ug/l) – Field Probe	1	323	23	18	1	112	10[7]	227	70%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	30	29	2	85	10[7]	18	72%
Hardness, Total (mg/l)	0.4	5	129.2	131.0	120.0	139.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	50	1.2	1.1	n.d.	4.5	-----	-----	-----
Nitrogen, Total (mg/)	0.1	50	1.3	1.2	n.d.	4.8	1[7]	30	60%
Nitrate-Nitrite N, Total (mg/l)	0.02	50	-----	0.03	n.d.	0.40	100[3]	0	0%
Phosphorus, Total (mg/l)	0.02	50	0.09	0.07	n.d.	0.54	0.05[7]	39	78%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	50	-----	n.d.	n.d.	0.19	-----	-----	-----
Suspended Solids, Total (mg/l)	4	30	-----	6	n.d.	55	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	333	750[5], 87[6]	0, 1	0, 20%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	88[5], 30[6]	0	0%
Arsenic, Dissolved (ug/l)	3	5	-----	3	n.d.	4	340[5], 16.7[8]	0	0%
Beryllium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	130[5], 5.3[6]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	7.7[5], 0.3[6]	0	0%
Chromium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	10	739[5], 96[6]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	2	17[5], 11[6]	0	0%
Lead, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	87[5], 3.3[6]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[5]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[6]	0	0%
Nickel, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	60	588[5], 65[6]	0,1	0%
Selenium, Total (ug/l)	2	5	-----	2	n.d.	2	20[3,5], 5[6]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.5[5]	0	0%
Thallium (ug/l)	6	5	-----	n.d.	n.d.	n.d.	1,400[5], 6.3[8]	0	0%
Zinc, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	147[5,6]	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.64	20[9]	0	0%
Acetochlor, Total (ug/l)[C]	0.05	15	-----	n.d.	n.d.	1.00	-----	-----	-----
Alachlor, Total (ug/l)[C]	0.05	10	-----	n.d.	n.d.	n.d.	760[5], 76[6]	0	0%
Atrazine, Total (ug/l)[C]	0.05	25	0.27	0.30	n.d.	0.70	330[5], 12[6]	0	0%
Metolachlor, Total (ug/l)[C]	0.05	25	-----	n.d.	n.d.	0.50	390[5], 100[6]	0	0%
Pesticide Scan (ug/l)[D]	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	1.00	-----	-----	-----
Atrazine		5	-----	n.d.	n.d.	0.35	330[5], 12[6]	0	0%
Profluralin		1	-----	0.48	0.48	0.48	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska's WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedance indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 2. Summary of water quality conditions monitored in Zorinsky Lake at site EZRLKML1B from May to September during the 5-year period 2006 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	25	1110.7	1110.5	1108.9	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	398	21.7	21.8	12.7	30.2	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	398	5.2	6.1	0.1	13.2	≥ 5(2)	164	41%
Dissolved Oxygen (% Sat.)	0.1	368	61.4	70.2	1.1	142.8	-----	-----	-----
Specific Conductance (umho/cm)	1	382	470	496	272	640	2,000(3)	0	0%
pH (S.U.)	0.1	368	7.8	7.9	6.7	8.8	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	368	35	13	1	1048	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	382	270	285	-136	425	-----	-----	-----
Secchi Depth (in.)	1	26	32	26	10	86	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	317	25	18	2	132	10(4)	228	72%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life.
* A highlighted mean or percent exceedance indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 3. Summary of water quality conditions monitored in Zorinsky Lake at site EZRLKML1A from May to September during the 2-year period 2009 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean(A)	Median	Min.	Max.	State WQS Criteria(B)	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	9	1110.8	1110.5	1110.3	1111.5	-----	-----	-----
Water Temperature (°C)	0.1	175	20.8	20.6	11.7	29.5	32(1)	0	0%
Dissolved Oxygen (mg/l)	0.1	175	4.7	4.3	0.1	12.4	≥ 5(2)	95	54%
Dissolved Oxygen (% Sat.)	0.1	175	54.5	49.2	0.7	148.3	-----	-----	-----
Specific Conductance (umho/cm)	1	175	500	543	311	646	2,000(3)	-----	-----
pH (S.U.)	0.1	175	7.8	7.7	6.8	8.7	≥6.5 & ≤9.0(1)	0	0%
Turbidity (NTUs)	1	175	16	12	0	308	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	175	222	243	-143	429	-----	-----	-----
Secchi Depth (in.)	1	10	27	24	18	38	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	175	35	29	8	139	10(4)	170	97%

n.d. = Not detected.
(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).
(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Nutrient criteria for aquatic life .
* A highlighted mean or percent exceedance indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 4. Summary of water quality conditions monitored in Zorinsky Lake at site EZRLKML2 from May to September during the 3-year period 2008 through 2010. [Note: Except for pool elevation and Secchi depth, results are for water column depth-profile measurements.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[(A)]	Median	Min.	Max.	State WQS Criteria[(B)]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	15	1111.1	1110.6	1110.3	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	195	22.3	22.3	13.9	30.2	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	195	6.2	6.6	0.2	13.0	≥ 5[(2)]	55	28%
Dissolved Oxygen (% Sat.)	0.1	195	74.4	80.9	2.1	144.1	-----	-----	-----
Specific Conductance (umho/cm)	1	195	437	388	225	642	2,000[(3)]	-----	-----
pH (S.U.)	0.1	195	8.0	8.0	7.0	8.9	≥6.5 & ≤9.0[(1)]	0	0%
Turbidity (NTUs)	1	195	81	17	1	1812	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	195	293	308	-127	443	-----	-----	-----
Secchi Depth (in.)	1	16	25	23	6	74	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	194	34	26	1	125	16[(4)]	163	84%

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.

(2) Use-specific criteria for aquatic life .

(3) Agricultural criteria for surface waters.

(4) Nutrient criteria for aesthetics.

* A highlighted mean or percent exceedance indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

Plate 5. Summary of water quality conditions monitored in Zorinsky Lake at site EZRLKUP1 from May to September during the 5-year period 2006 through 2010. [Note: Results for water temperature, dissolved oxygen, conductivity, pH, turbidity, ORP, and chlorophyll *a* (field probe) are for water column depth-profile measurements. Results for other parameters are for “grab samples” collected at ½ the Secchi depth.]

Parameter	Monitoring Results						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean[A]	Median	Min.	Max.	State WQS Criteria[B]	No. of WQS Exceedances	Percent WQS Exceedance
Pool Elevation (ft-NGVD29)	0.1	26	1110.7	1110.5	1108.9	1115.0	-----	-----	-----
Water Temperature (°C)	0.1	157	23.0	23.4	13.1	31.1	32[(1)]	0	0%
Dissolved Oxygen (mg/l)	0.1	157	7.4	6.9	0.5	15.9	≥ 5[(2)]	25	16%
Dissolved Oxygen (% Sat.)	0.1	145	89.5	83.9	6.9	171.8	-----	-----	-----
Specific Conductance (umho/cm)	1	151	438	445	167	621	2,000[(3)]	0	0%
pH (S.U.)	0.1	151	8.1	8.1	7.2	8.8	≥6.5 & ≤9.0[(1)]	0, 5	0%, 3%
Turbidity (NTUs)	1	143	174	38	13	3754	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	151	306	307	-34	444	-----	-----	-----
Secchi Depth (in.)	1	26	15	14	2	30	-----	-----	-----
Alkalinity, Total (mg/l)	7	25	131	130	98	170	>20[(1)]	0	0%
Ammonia, Total (mg/l)	0.02	25	-----	0.06	n.d.	0.34	6.95 [(4,5)], 1.18 [(4,6)]	0	0%
Chlorophyll *a* (ug/l) – Field Probe	1	119	33	28	n.d.	152	10[(7)]	97	82%
Chlorophyll *a* (ug/l) – Lab Determined	1	25	37	36	n.d.	132	10[(7)]	18	72%
Hardness, Total (mg/l)	0.4	5	130.4	134.0	120.0	136.0	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	25	1.1	1.1	n.d.	3.1	-----	-----	-----
Nitrogen, Total (mg/)	0.1	25	1.3	1.2	n.d.	3.9	1 [(7)]	17	68%
Nitrate-Nitrite N, Total (mg/l)	0.02	25	-----	0.05	n.d.	0.80	100[(3)]	0	0%
Phosphorus, Total (mg/l)	0.02	25	0.11	0.11	0.02	0.23	0.05[(7)]	23	92%
Phosphorus-Ortho, Dissolved (mg/l)	0.02	25	-----	0.02	n.d.	0.08	-----	-----	-----
Suspended Solids, Total (mg/l)	4	25	24	22	5	68	-----	-----	-----
Aluminum, Dissolved (ug/l)	25	5	-----	n.d.	n.d.	5	750[(5)], 87[(6)]	0	0%
Antimony, Dissolved (ug/l)	6	5	-----	n.d.	n.d.	n.d.	88[(5)], 30[(6)]	0	0%
Arsenic, Dissolved (ug/l)	3	5	-----	3	n.d.	4	340[(5)], 16.7[(8)]	0	0%
Beryllium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	130[(5)], 5.3[(6)]	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	7.8[(5)], 0.3[(6)]	0	0%
Chromium, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	752 [(5)], 98[(6)]	0	0%
Copper, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	18[(5)], 12[(6)]	0	0%
Lead, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	89[(5)], 3.5[(6)]	0	0%
Mercury, Dissolved (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	1.4[(5)]	0	0%
Mercury, Total (ug/l)	0.05	5	-----	n.d.	n.d.	n.d.	0.77[(6)]	0	0%
Nickel, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	600[(5)], 67[(6)]	0	0%
Selenium, Total (ug/l)	2	5	-----	2	n.d.	2	20[(3,5)], 5[(6)]	0	0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	5.7[(5)]	0	0%
Thallium (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	1,400[(5)], 6.3[(8)]	0	0%
Zinc, Dissolved (ug/l)	10	5	-----	n.d.	n.d.	n.d.	150[(5,6)]	0	0%
Microcystin, Total (ug/l)	0.05	25	-----	n.d.	n.d.	0.40	20[(9)]	0	0%
Acetochlor, Total (ug/l)[(C)]	0.05	15	-----	0.10	n.d.	0.80	-----	-----	-----
Alachlor, Total (ug/l)[(C)]	0.05	10	-----	n.d.	n.d.	0.05	760[(5)], 76[(6)]	0	0%
Atrazine, Total (ug/l)[(C)]	0.05	25	0.28	0.20	n.d.	0.80	330[(5)], 12[(6)]	0	0%
Metolachlor, Total (ug/l)[(C)]	0.05	20	-----	n.d.	n.d.	0.40	390[(5)], 100[(6)]	0	0%
Pesticide Scan (ug/l)[(D)]	0.05						-----	-----	-----
Acetochlor		5	-----	n.d.	n.d.	0.20	-----	-----	-----
Atrazine		5	-----	n.d.	n.d.	0.37	330[(5)], 12[(6)]	0	0%
Metolachlor		5	-----	n.d.	n.d.	0.13	390[(5)], 100[(6)]	0	0%
Metribuzin		5	-----	n.d.	n.d.	0.10	100[(6)]	0	0%
Profluralin		1	-----	0.59	0.59	0.59	-----	-----	-----

n.d. = Not detected.

(A) Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean (i.e., log conversion of logarithmic pH values was not done to calculate mean).

(B) (1) General criteria for aquatic life.
(2) Use-specific criteria for aquatic life.
(3) Agricultural criteria for surface waters.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are calculated for median pH and temperature values.
(5) Acute criteria for aquatic life.
(6) Chronic criteria for aquatic life.
(7) Nutrient criteria for aquatic life.
(8) Human health criteria.
(9) Nebraska utilizes the World Health Organization recommended criterion of 20 ug/l microcystins in recreation water for impairment assessment.
Note: Many of Nebraska’s WQS criteria for metals are hardness based. As appropriate, listed criteria were calculated using the median hardness.

(C) Immunoassay analysis.

(D) The pesticide scan (GCMS) includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, deethylatrazine, deisopropylatrazine, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, metolachlor, metribuzin, pendimethalin, phorate, prometon, prometryn, propachlor, propazine, simazine, terbufos, triallate, and trifluralin. Individual pesticides were not detected unless listed under pesticide scan.

* A highlighted mean or percent exceedance indicates use impairment based on State of Nebraska 2010 Section 303(d) impairment assessment criteria.

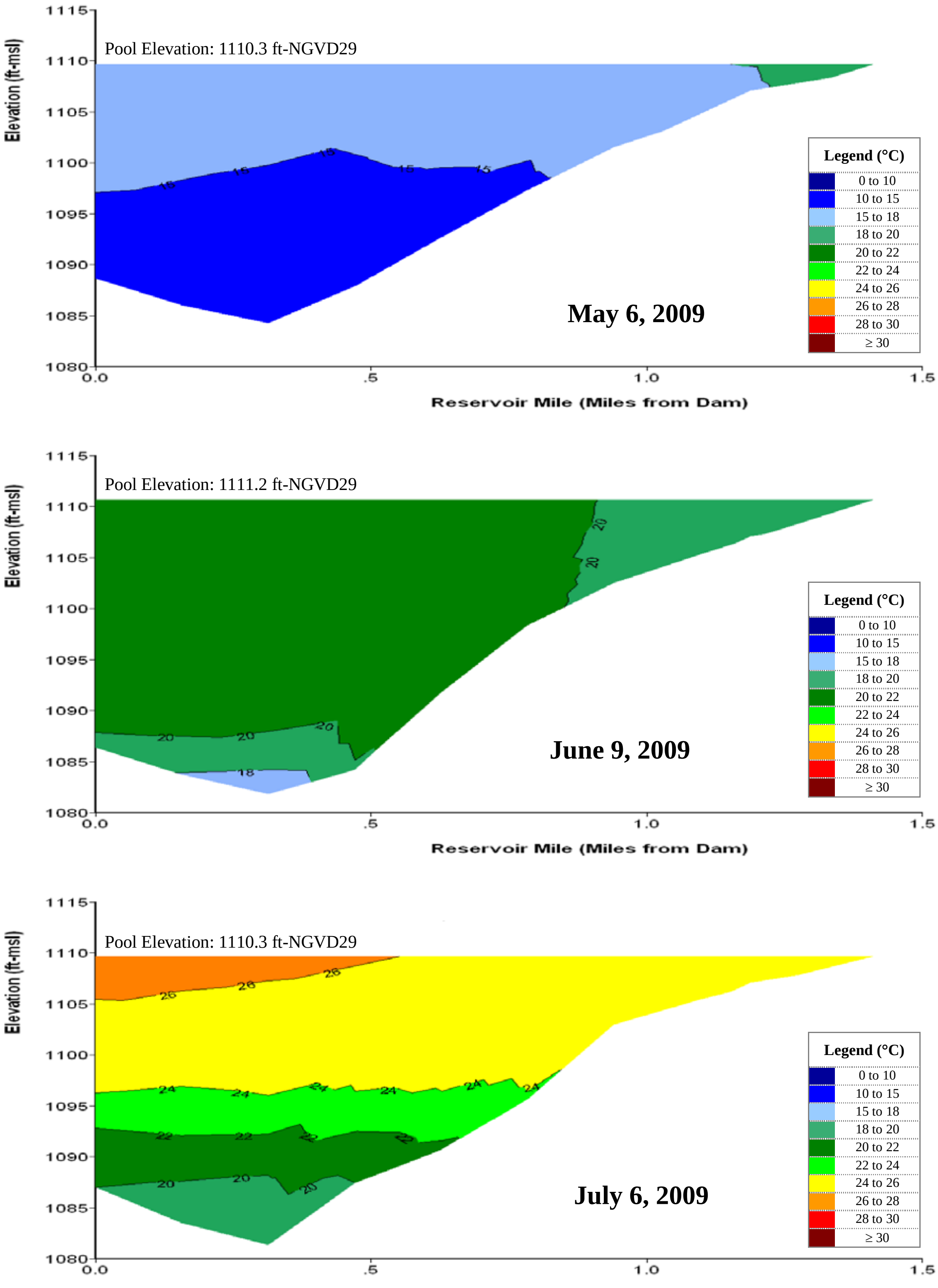
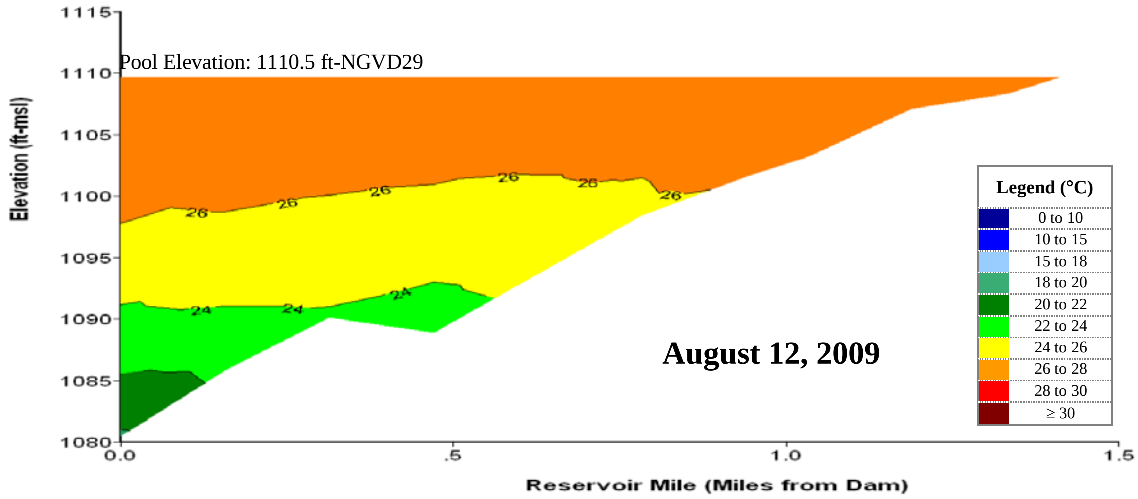


Plate 6. Longitudinal water temperature contour plots of Zorinsky Lake based on depth-profile water temperatures (°C) measured from May to September 2009.



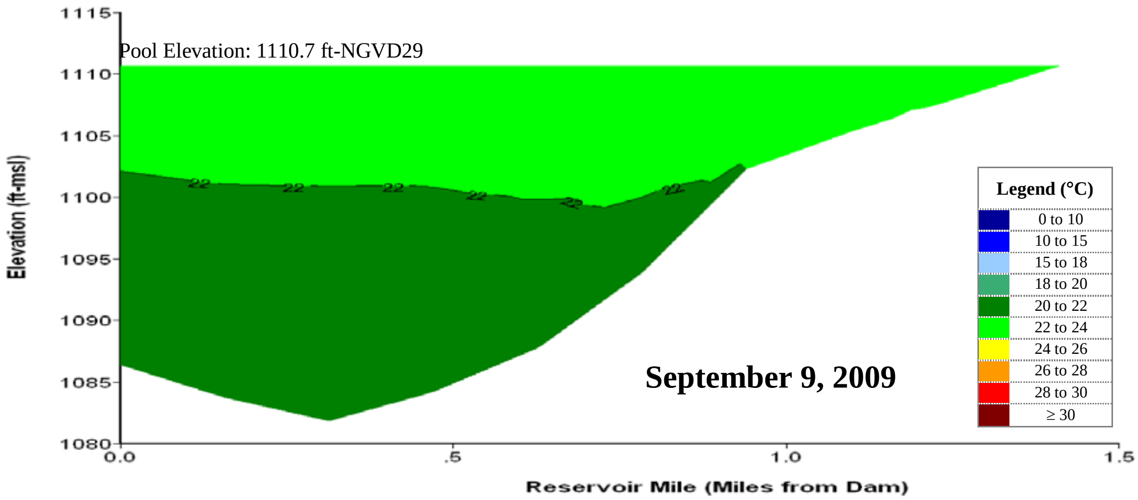


Plate 6. (Continued).

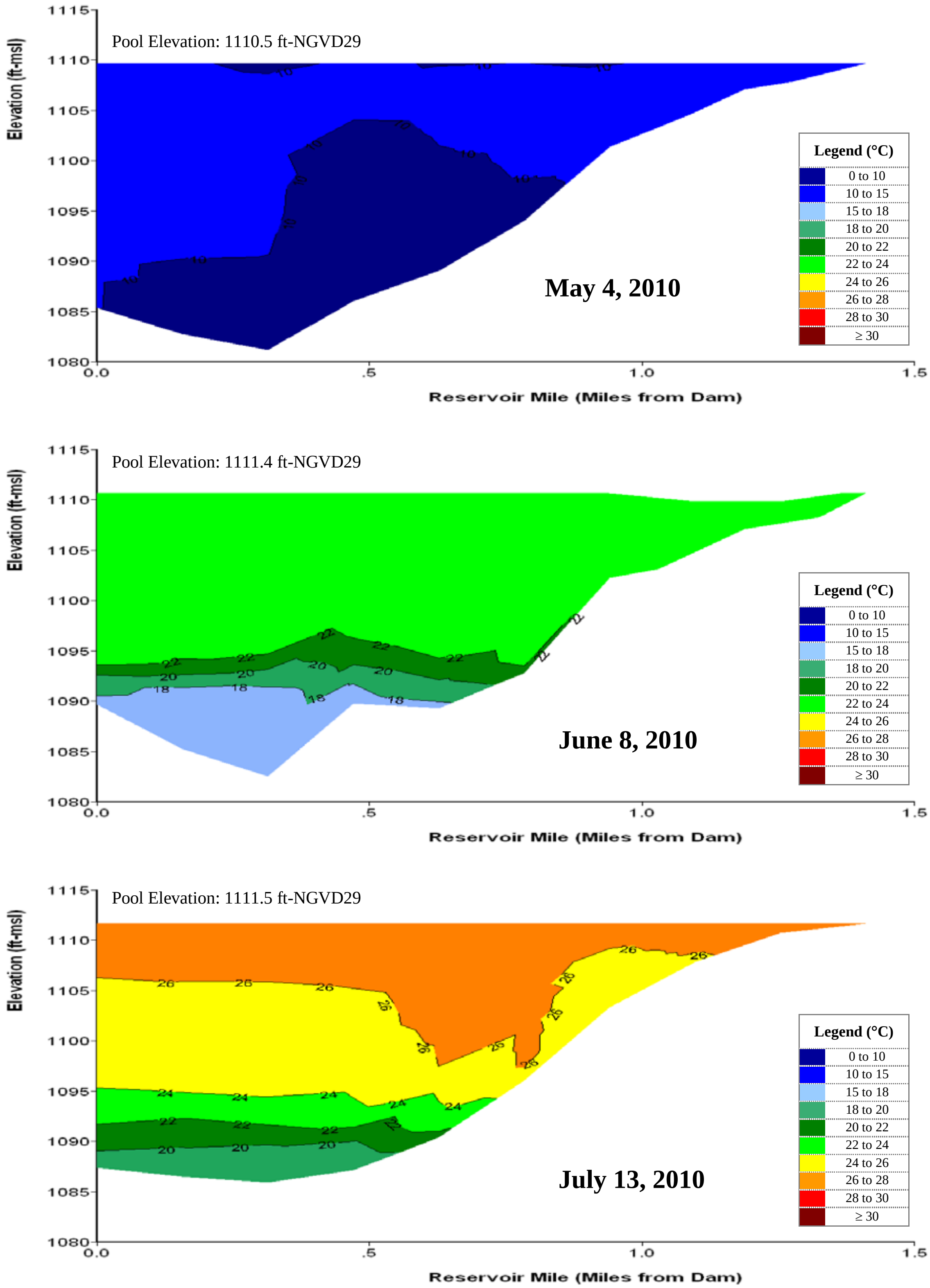
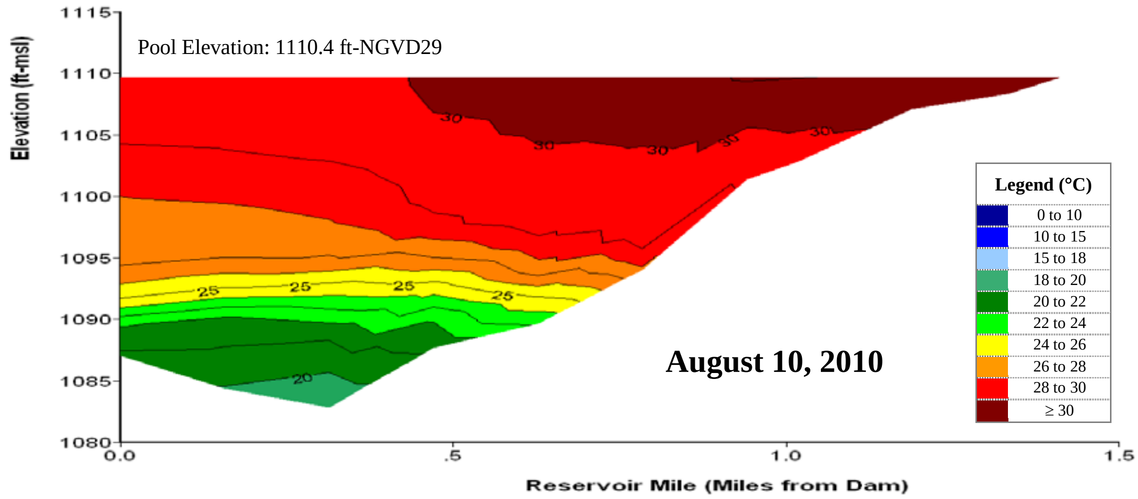


Plate 7. Longitudinal water temperature contour plots of Zorinsky Lake based on depth-profile water temperatures (°C) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



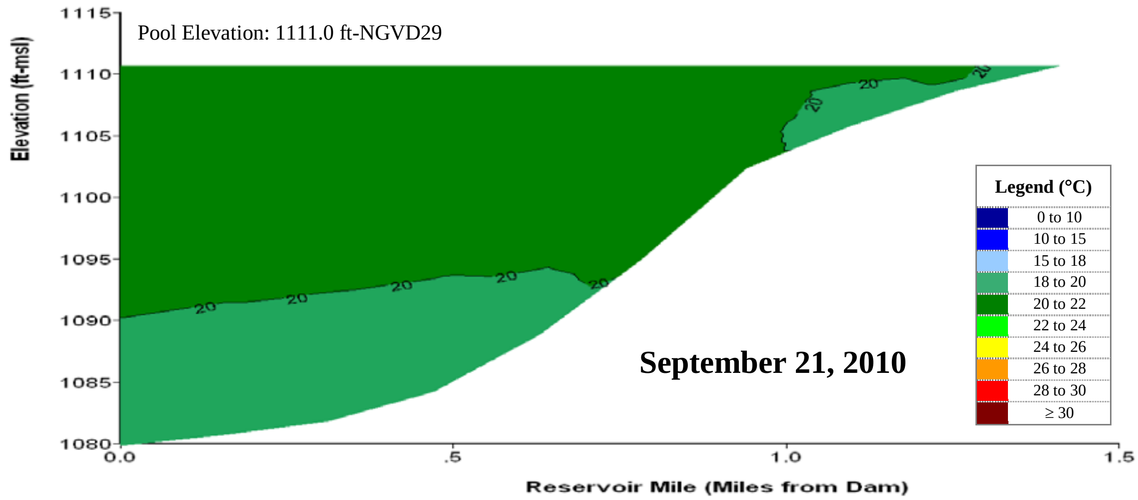


Plate 7. (Continued).

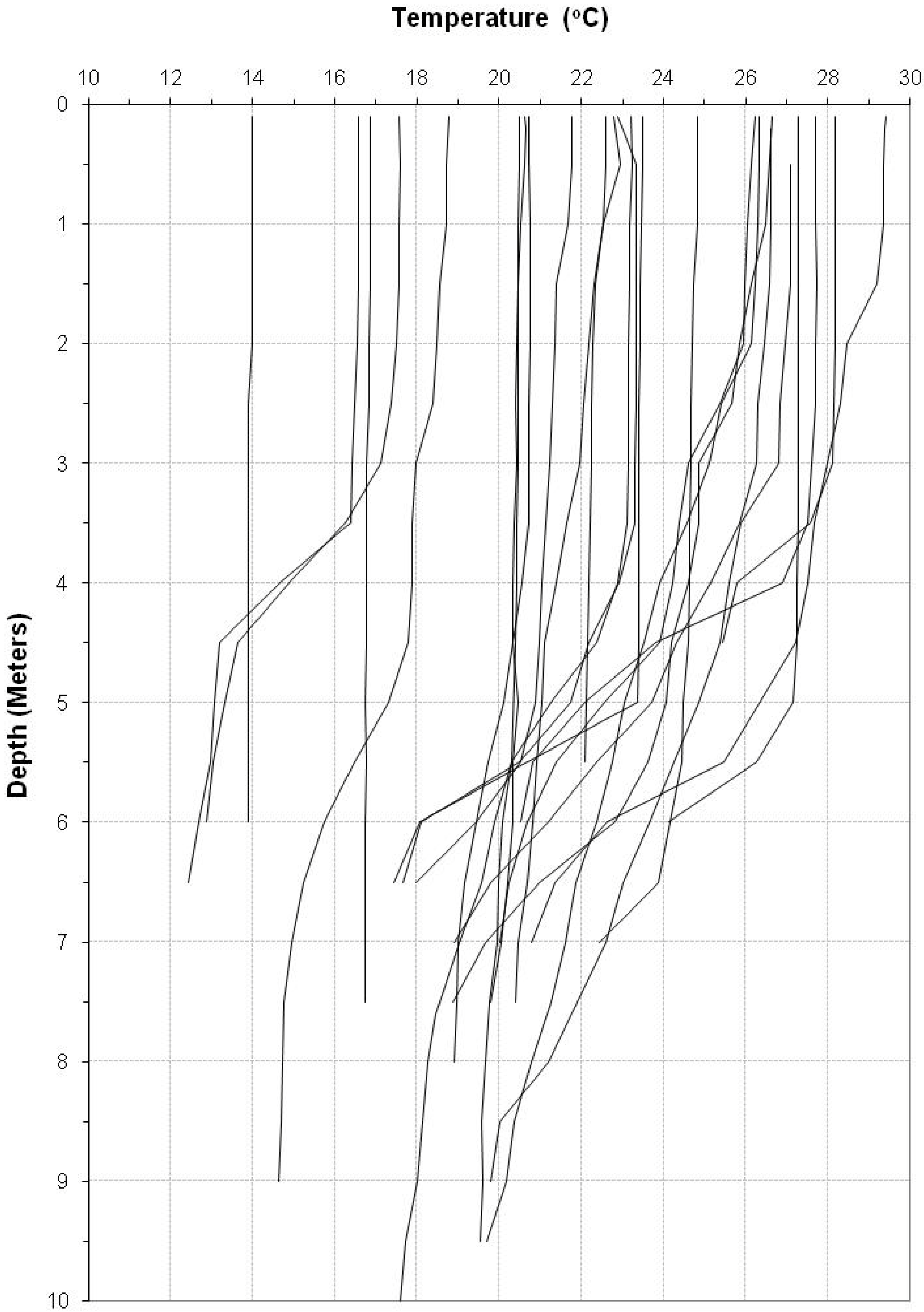


Plate 8. Temperature depth profiles for Zorinsky Lake compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 2010.

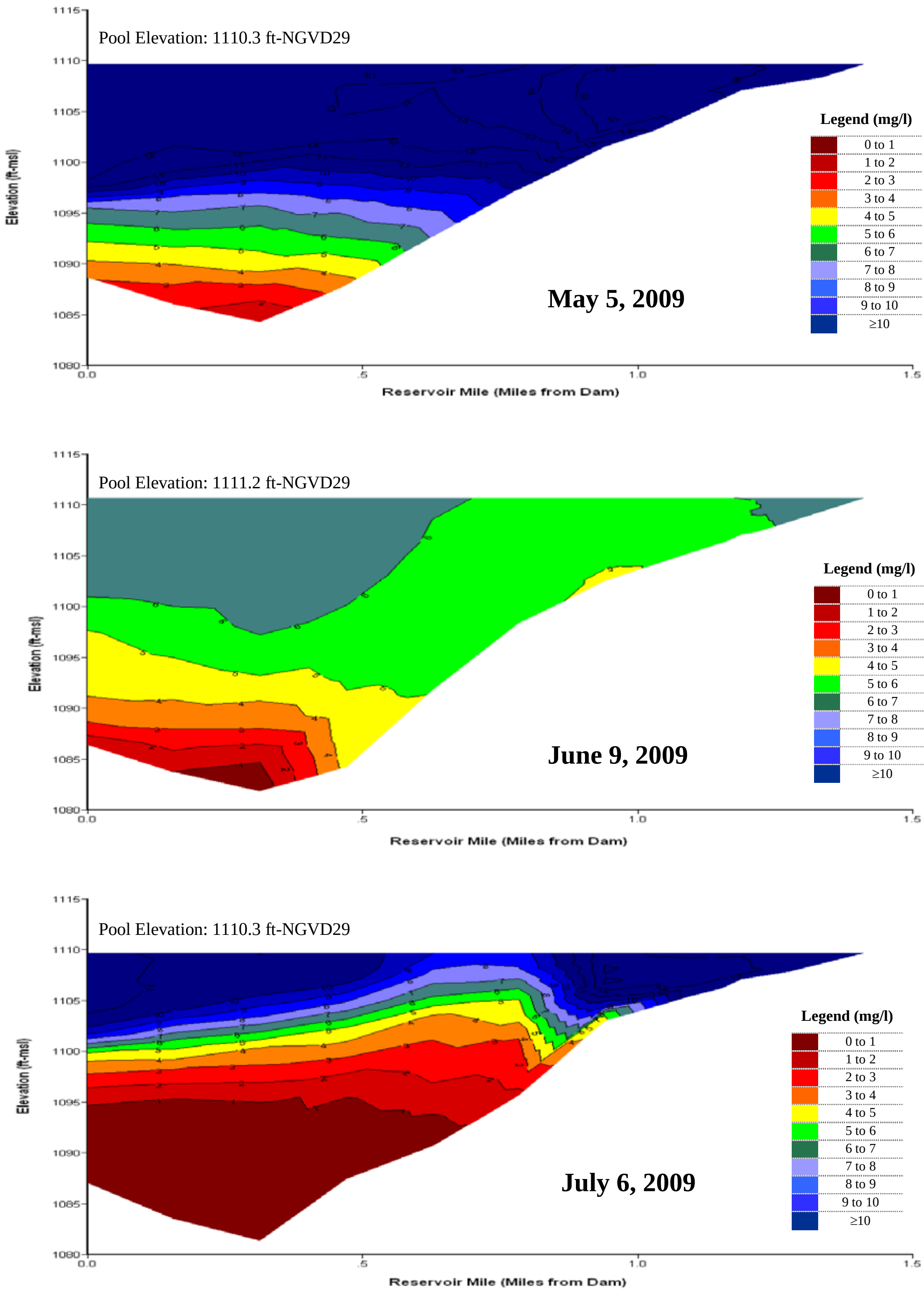
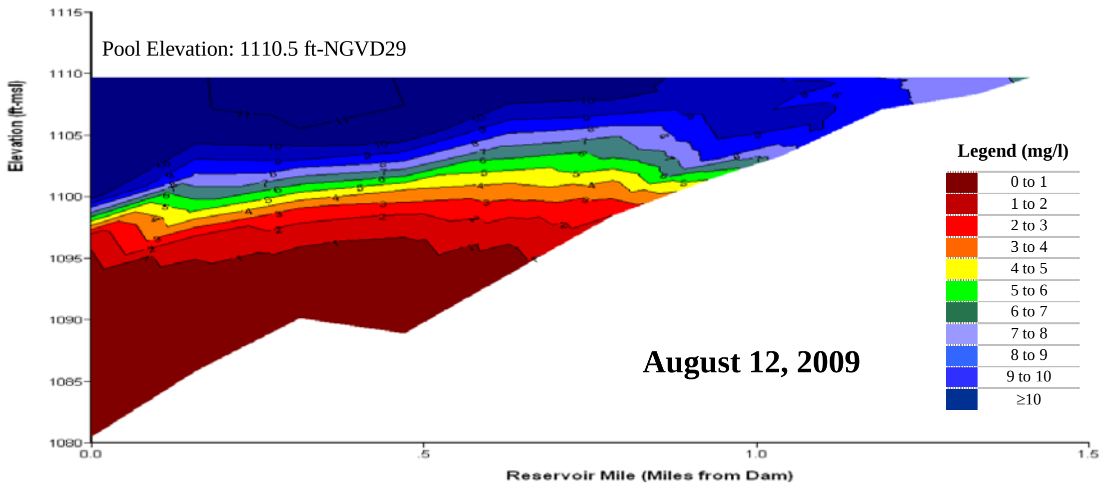


Plate 9. Longitudinal dissolved oxygen contour plots of Zorinsky Lake based on depth-profile dissolved oxygen concentrations (mg/l) measured from May to September 2009.



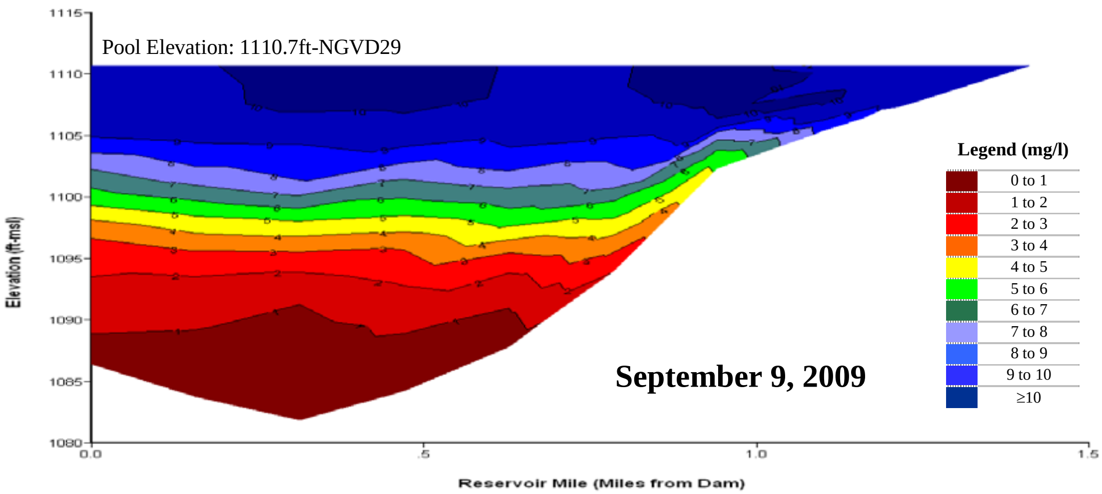


Plate 9. (Continued).

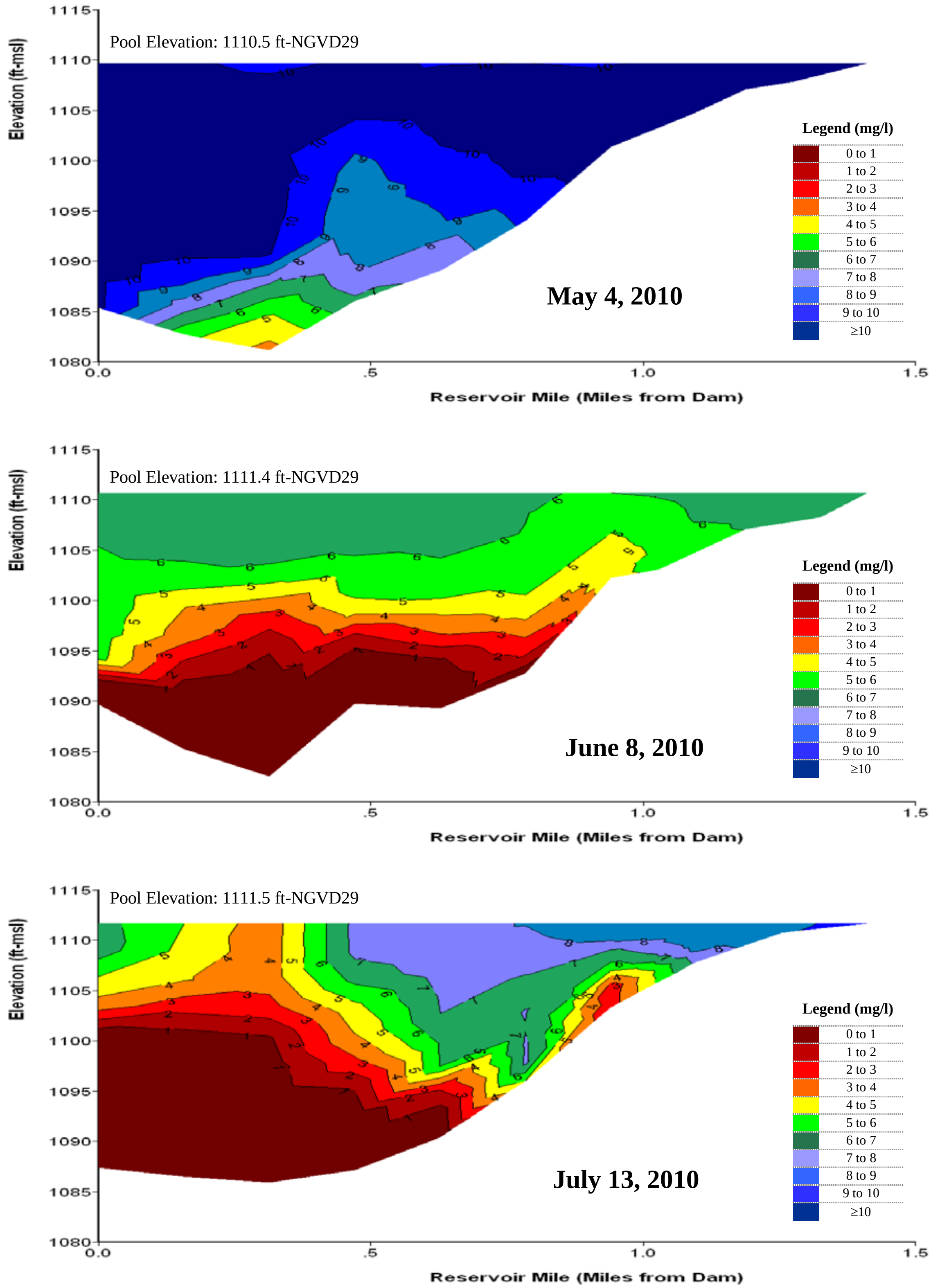
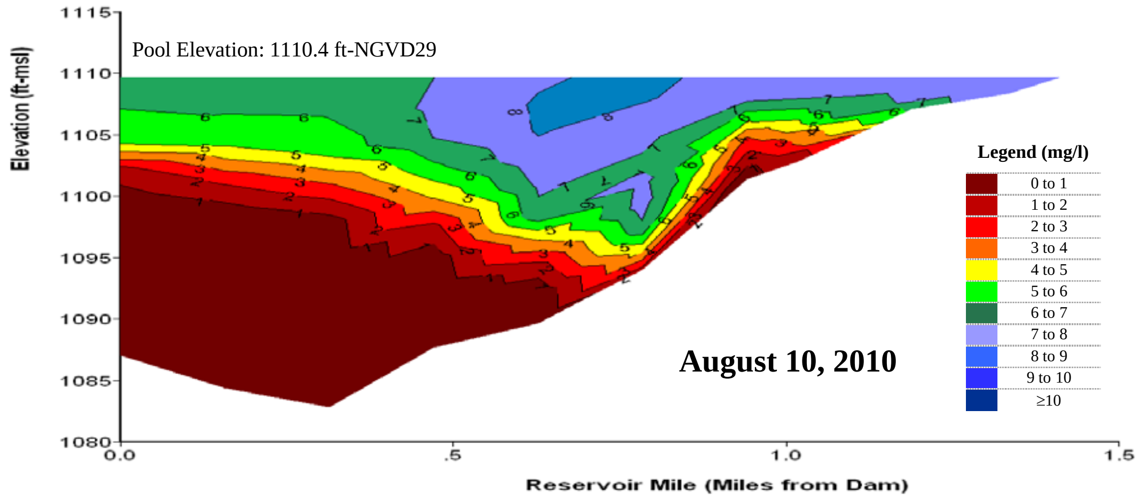


Plate 10. Longitudinal dissolved oxygen contour plots of Zorinsky Lake based on depth-profile dissolved oxygen concentrations (mg/l) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



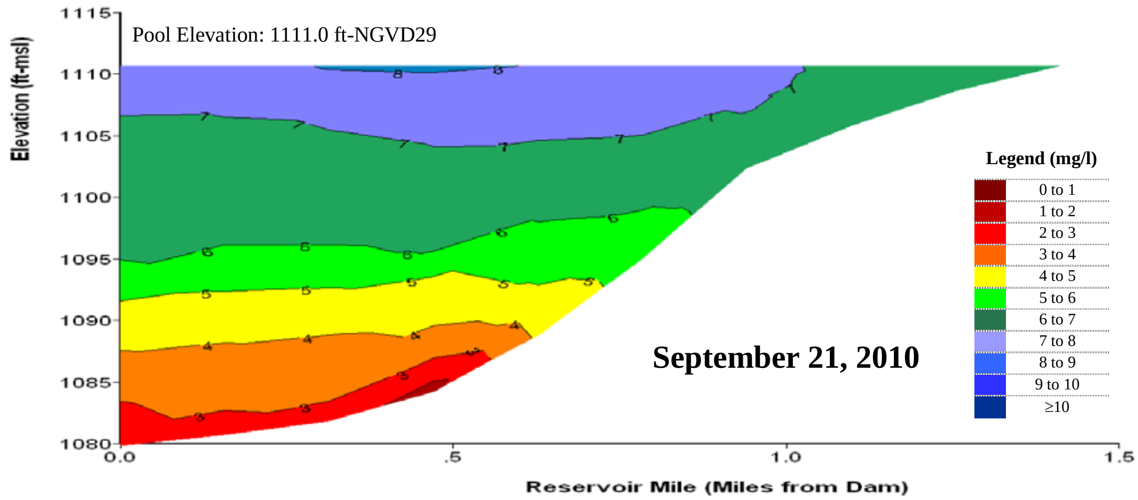


Plate 10. (Continued).

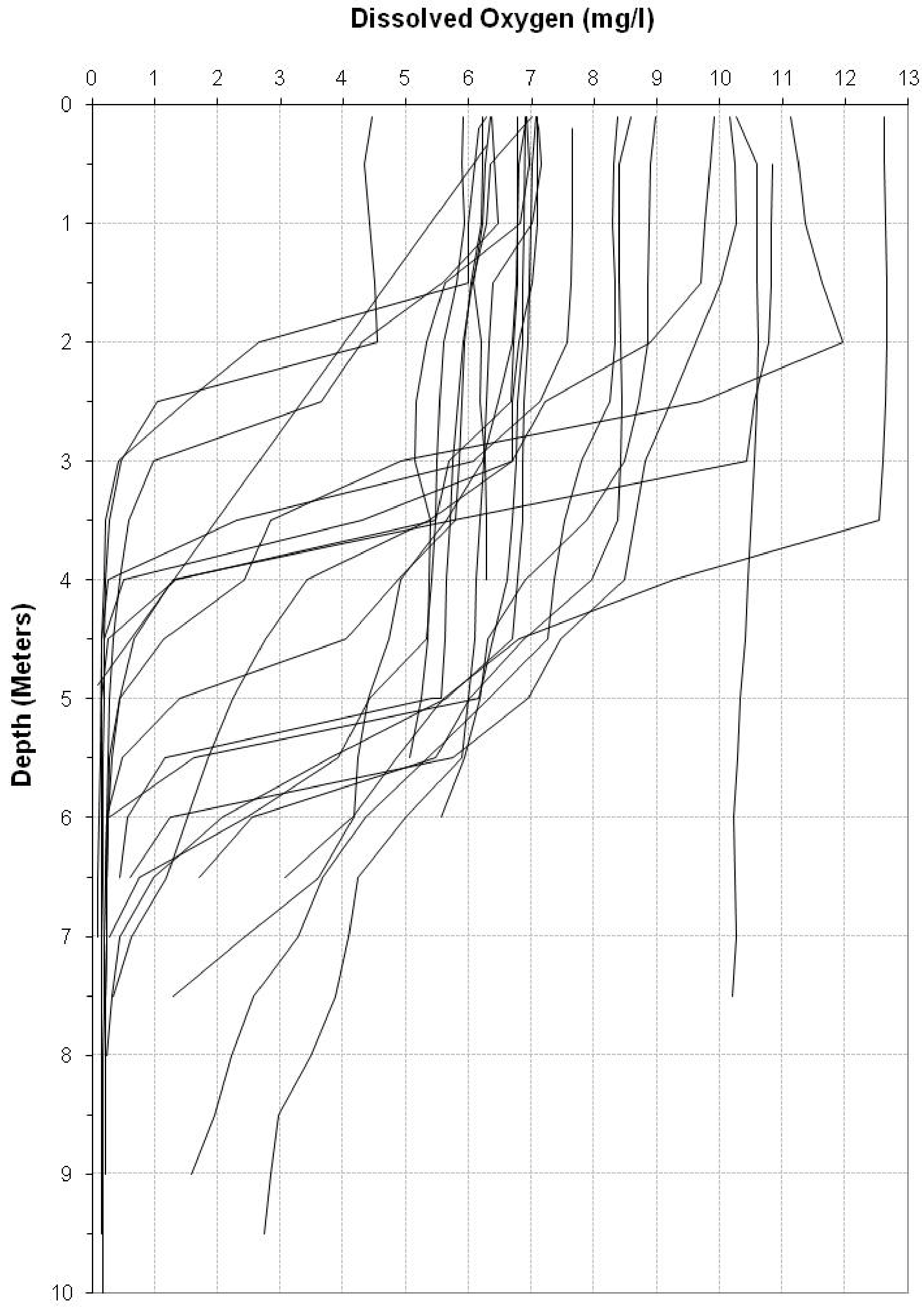


Plate 11. Dissolved oxygen depth profiles for Zorinsky Lake compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 2010.

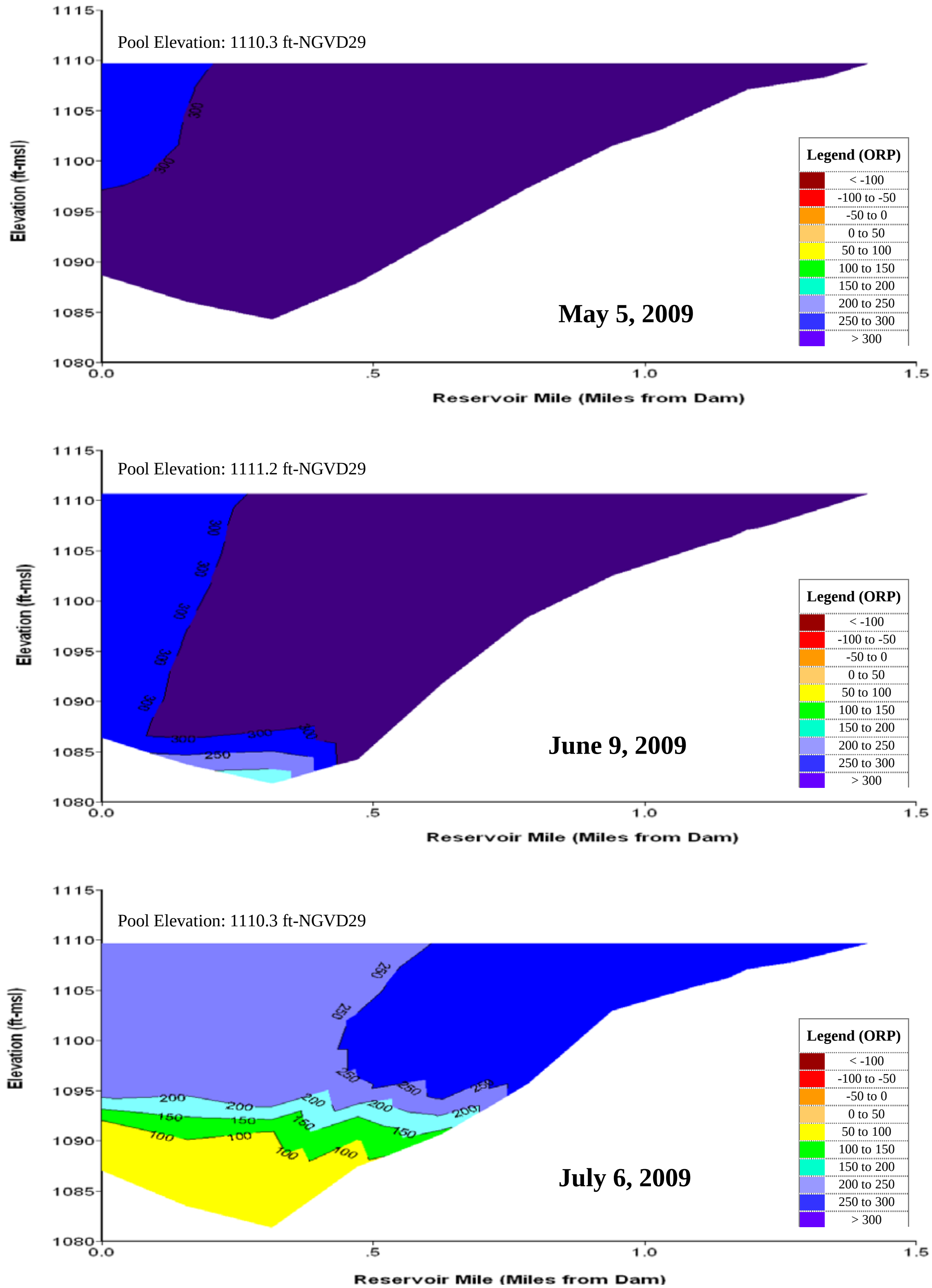
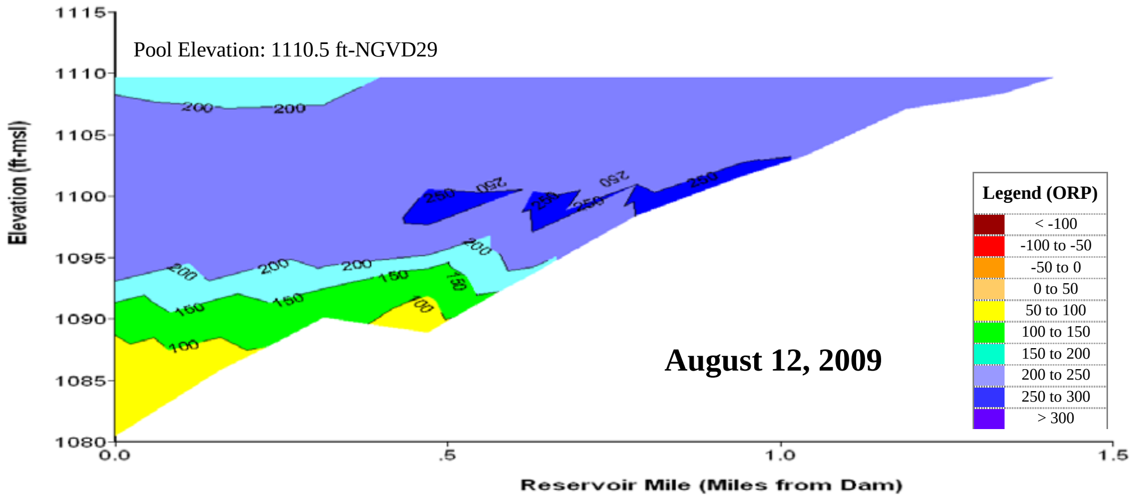


Plate 12. Longitudinal oxidation-reduction potential (ORP) contour plots of Zorinsky Lake based on depth-profile ORP levels (mV) measured from May to September 2009.



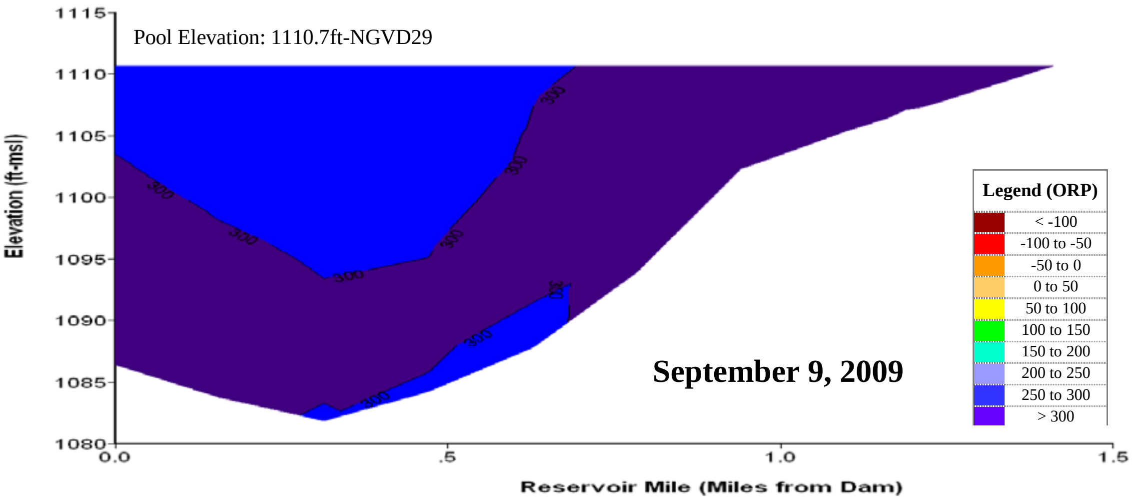


Plate 12. (Continued).

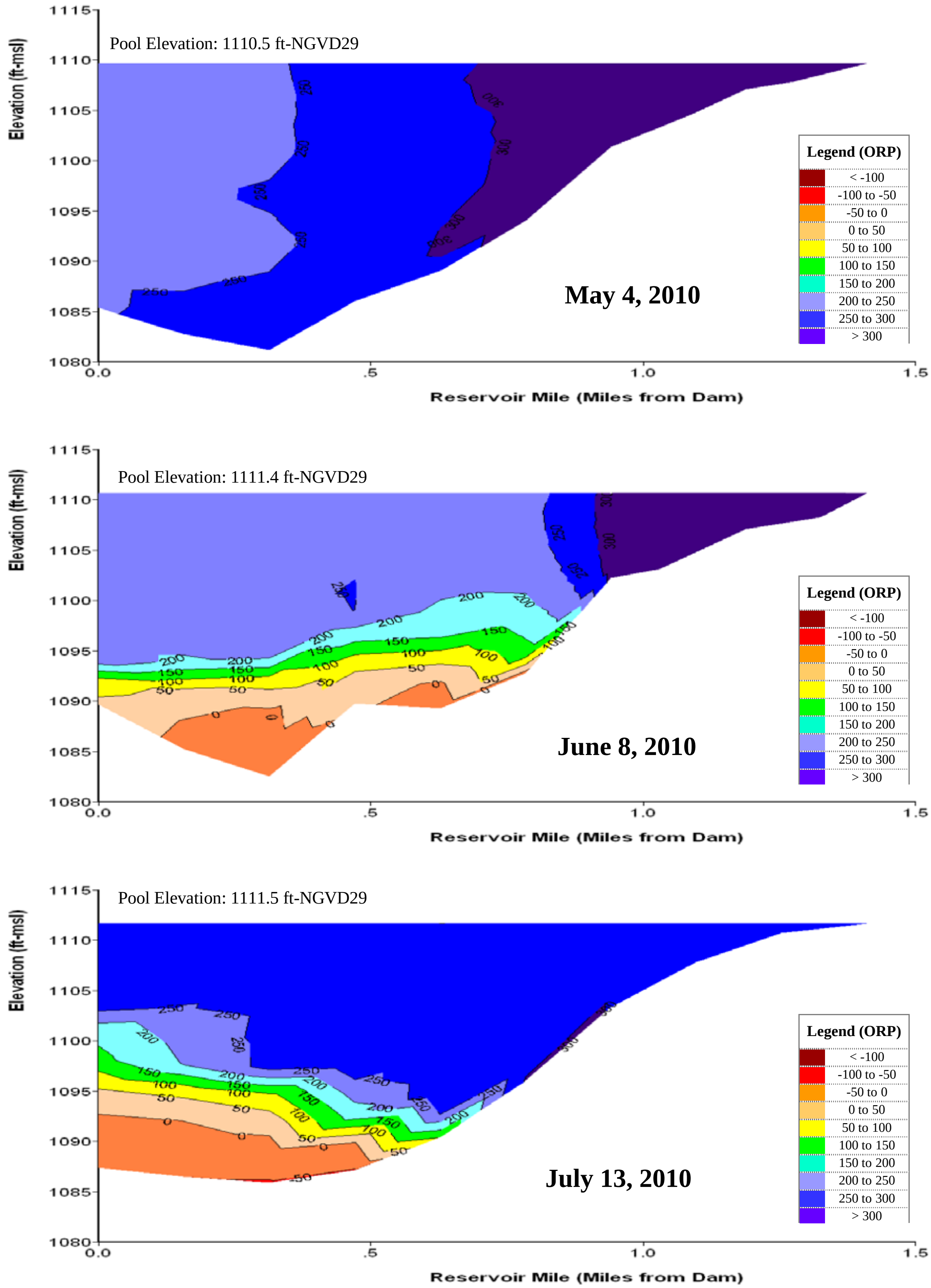
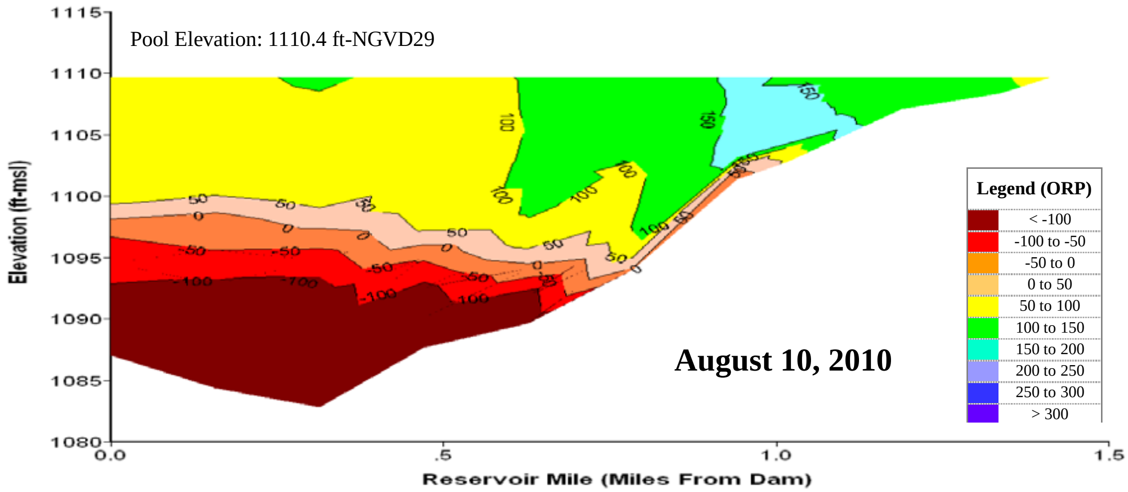


Plate 13. Longitudinal oxidation-reduction potential (ORP) contour plots of Zorinsky Lake based on depth-profile ORP levels (mV) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



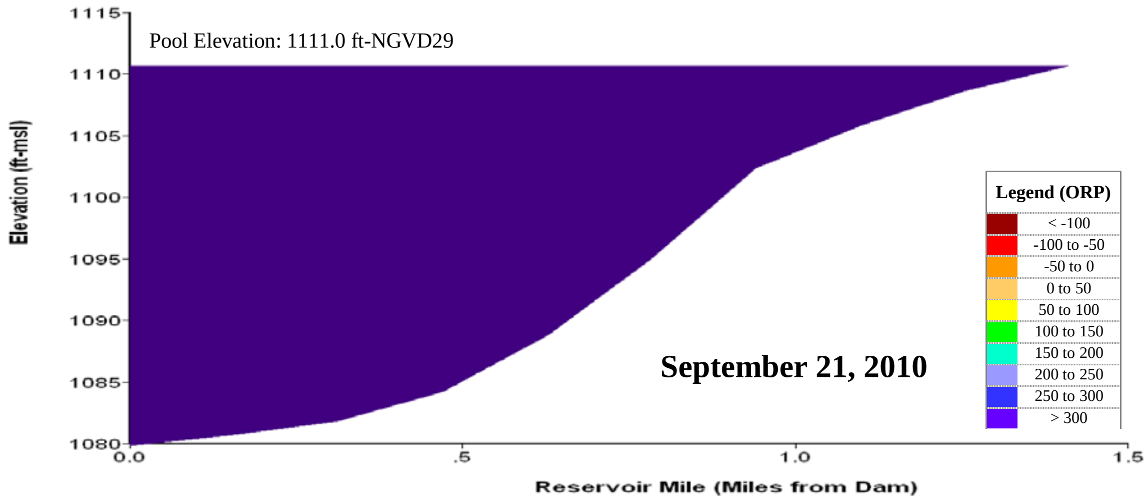


Plate 13. (Continued).

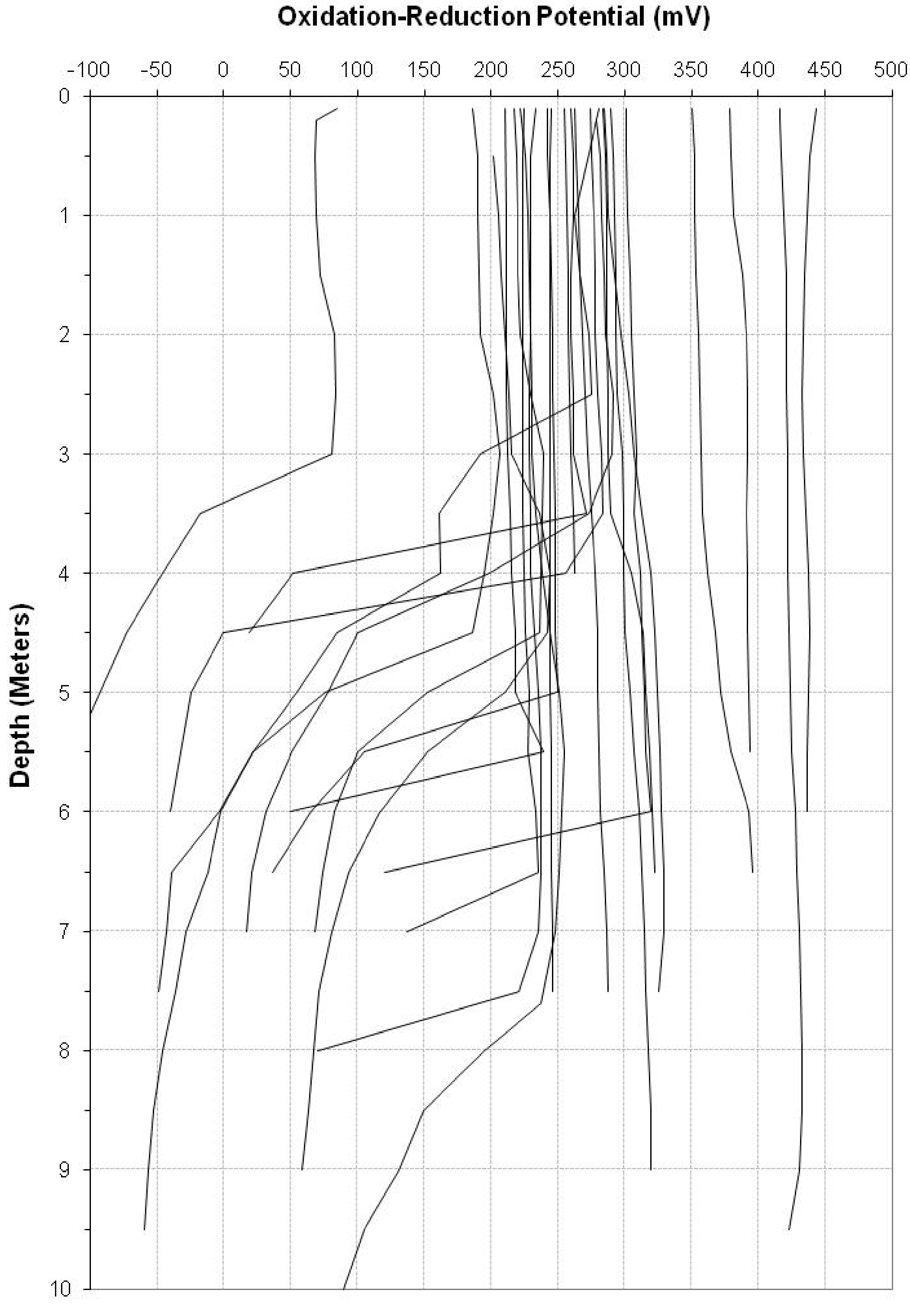


Plate 14. Oxidation-reduction potential depth profiles for Zorinsky Lake compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 2010.

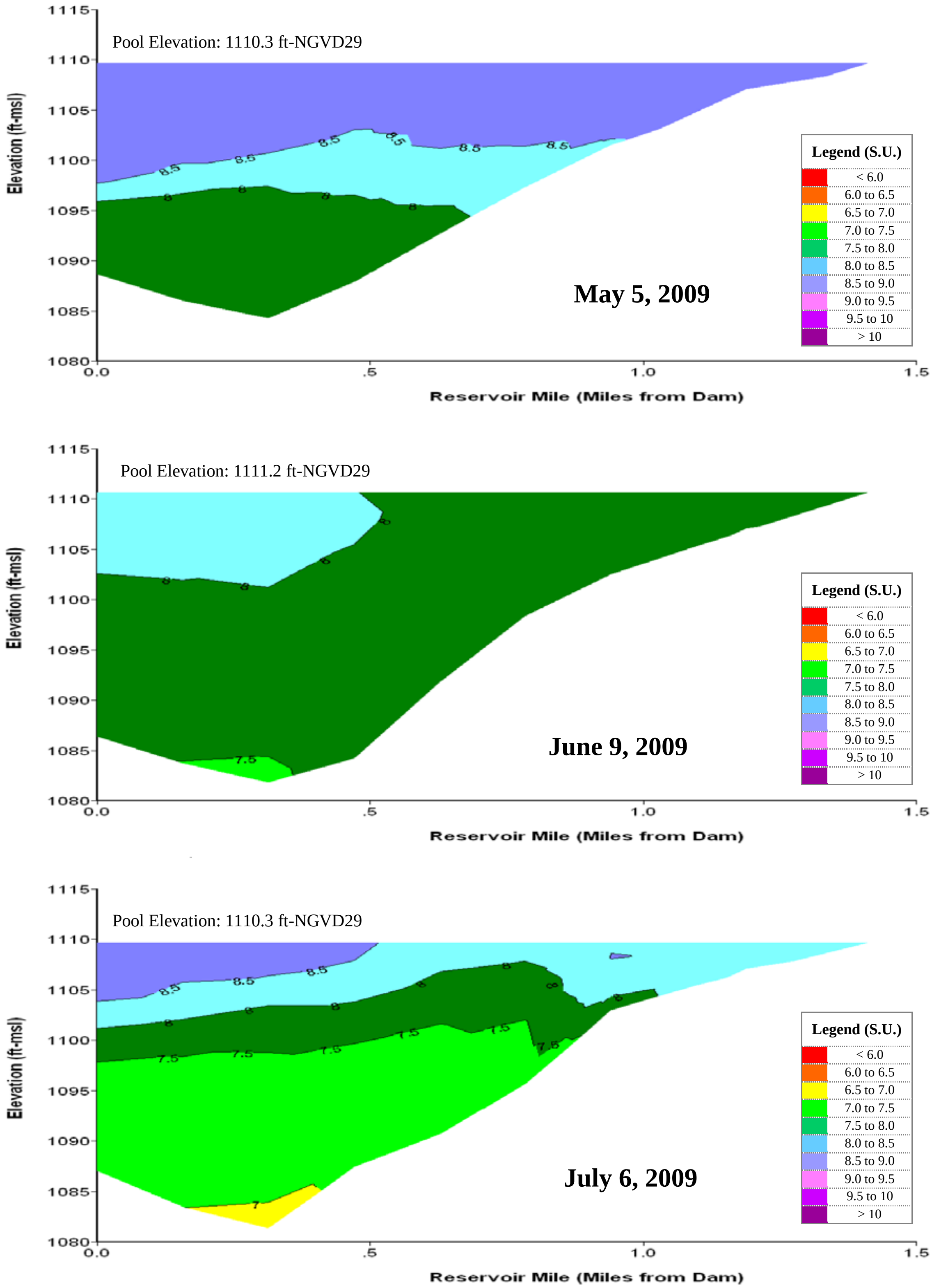
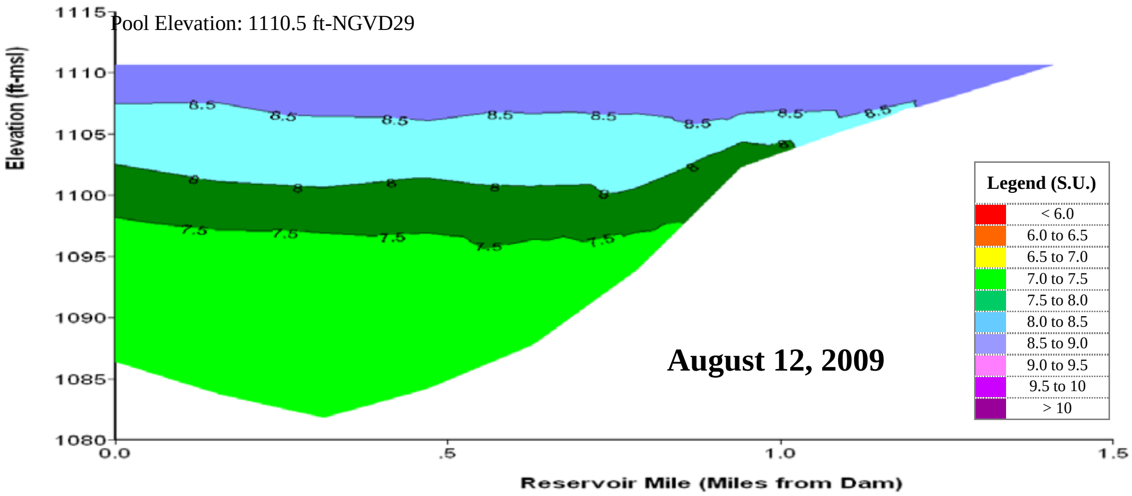


Plate 15. Longitudinal pH contour plots of Zorinsky Lake based on depth-profile pH levels (S.U.) measured from May to September 2009.



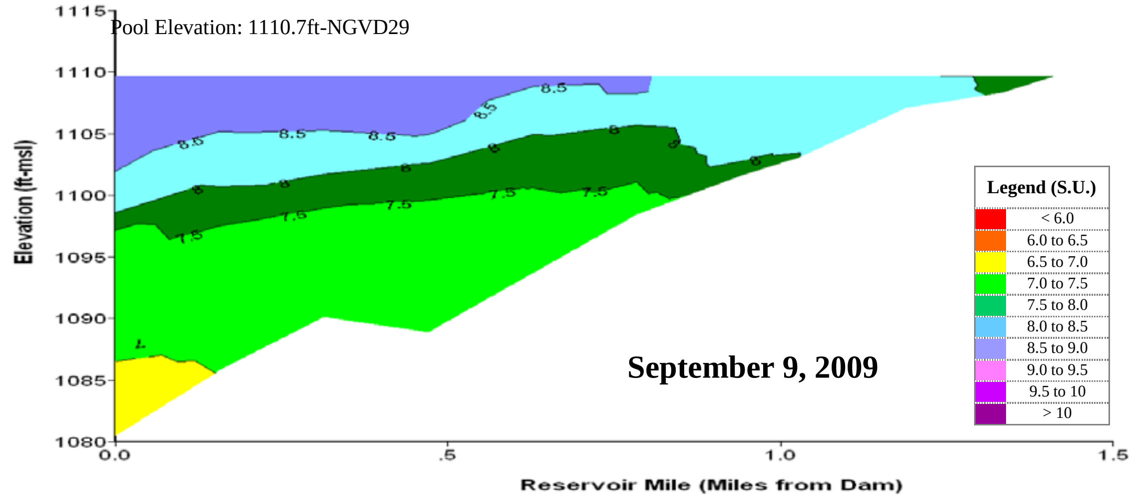


Plate 15. (Continued).

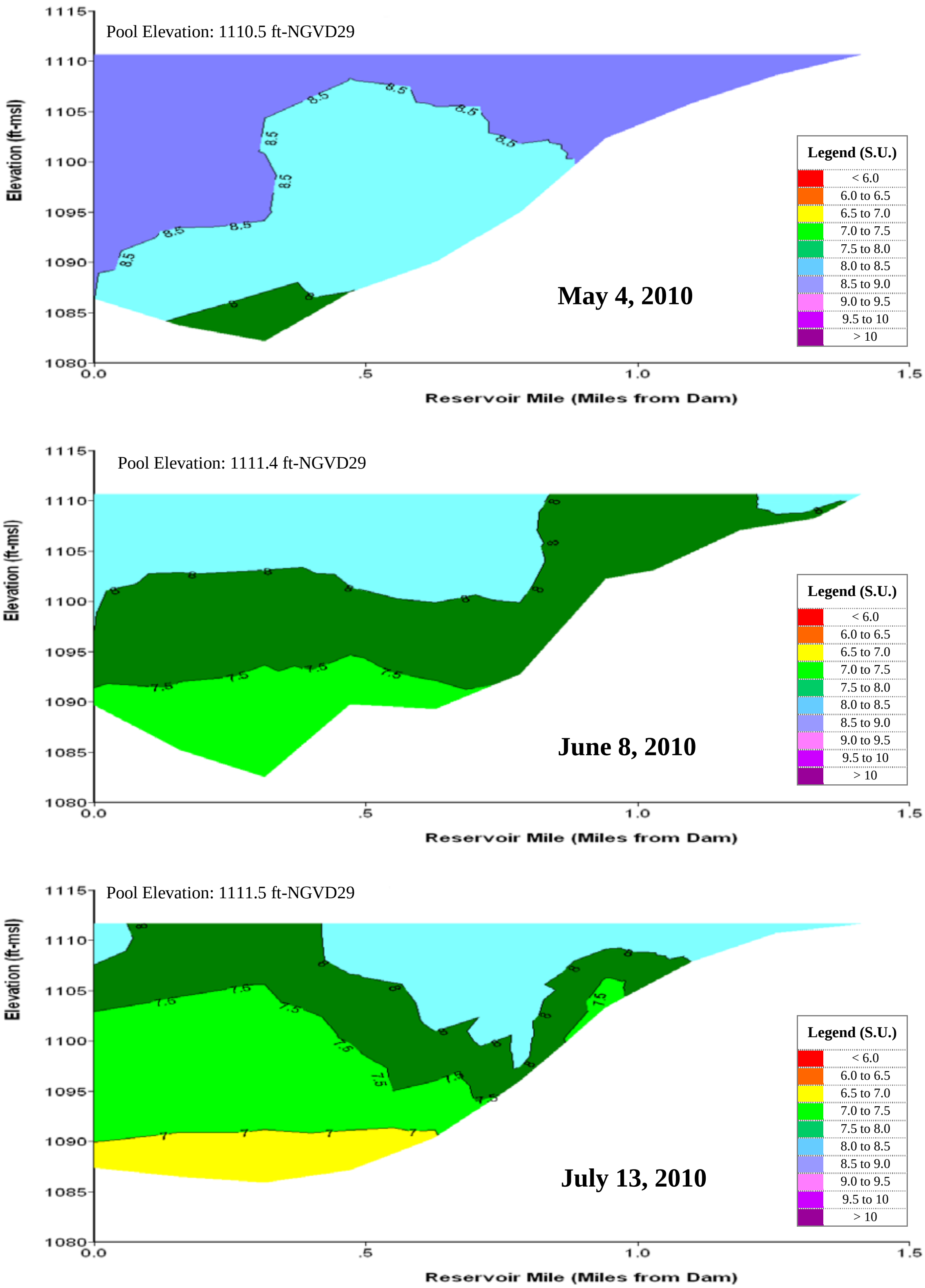
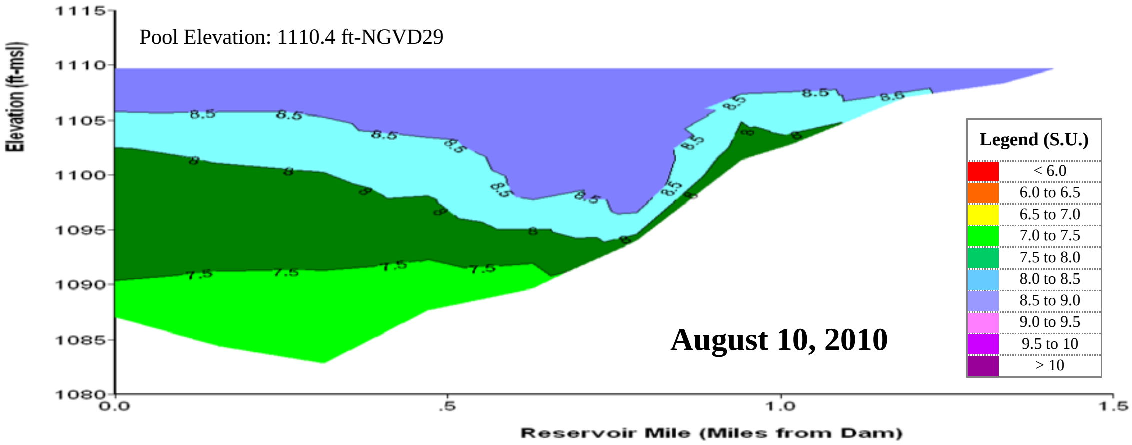


Plate 16. Longitudinal pH contour plots of Zorinsky Lake based on depth-profile pH levels (S.U.) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



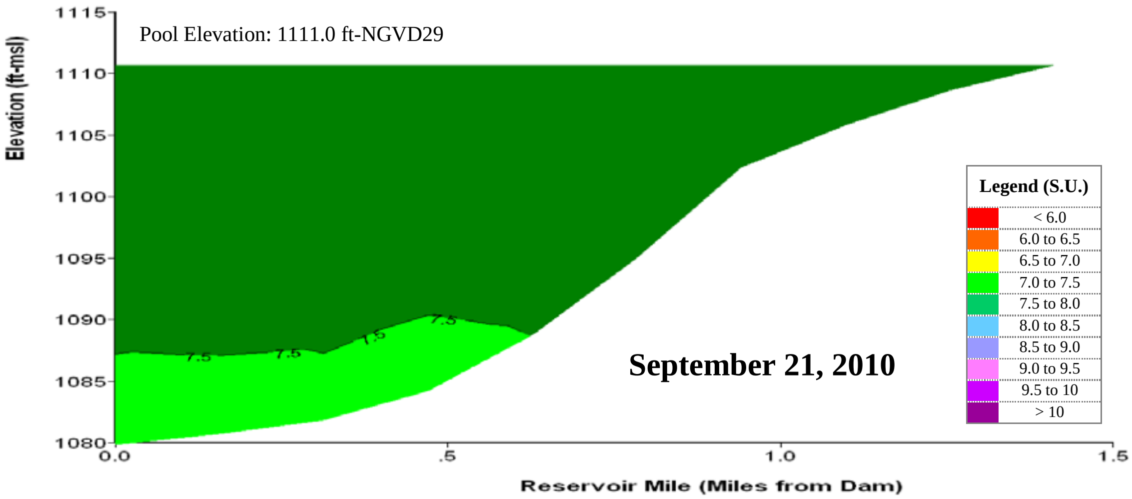


Plate 16. (Continued).

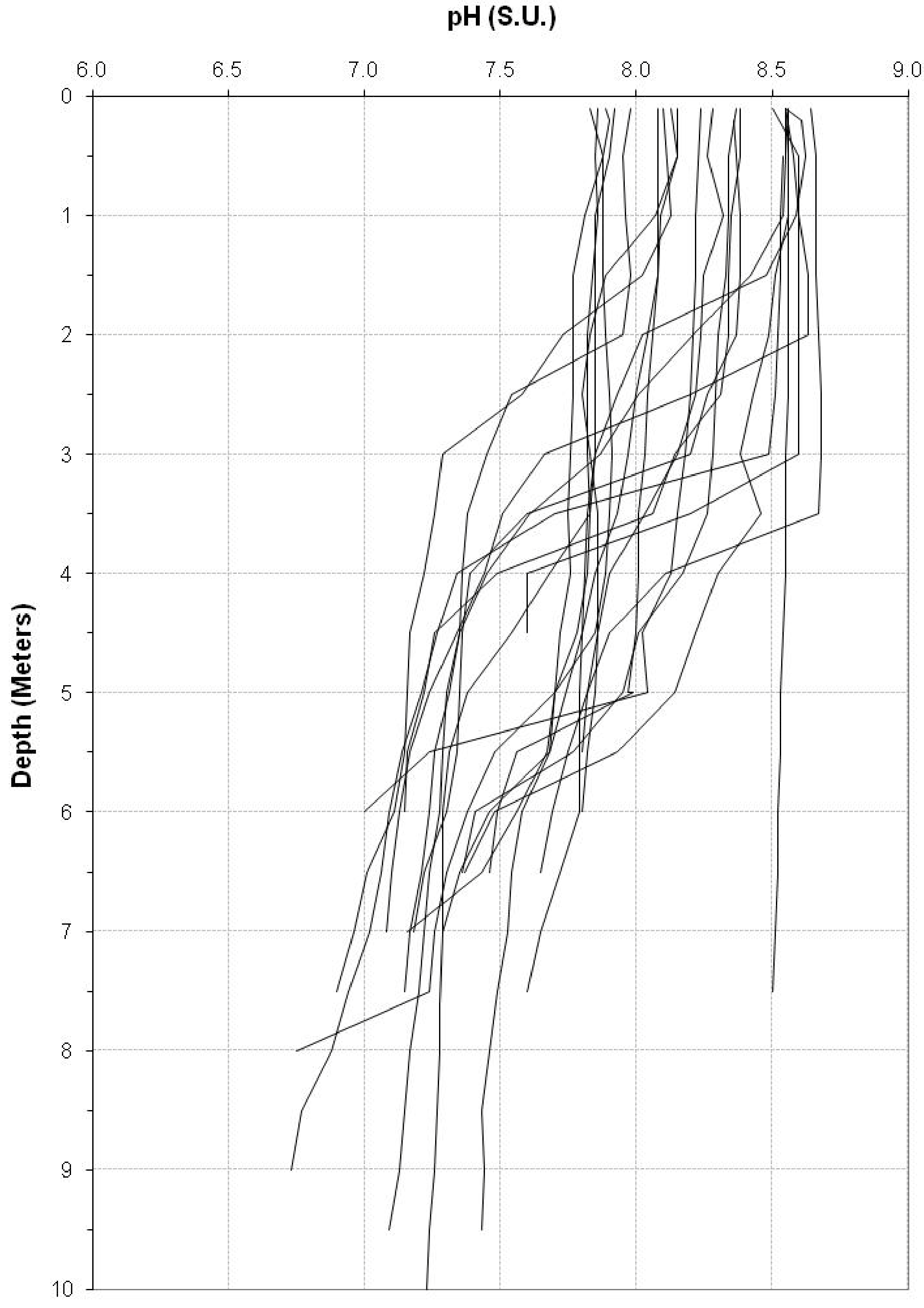


Plate 17. pH depth profiles for Zorinsky Lake compiled from data collected at the near-dam, deepwater ambient monitoring site (i.e., EZRLKND1) during the summer over the 5-year period of 2006 through 20010.

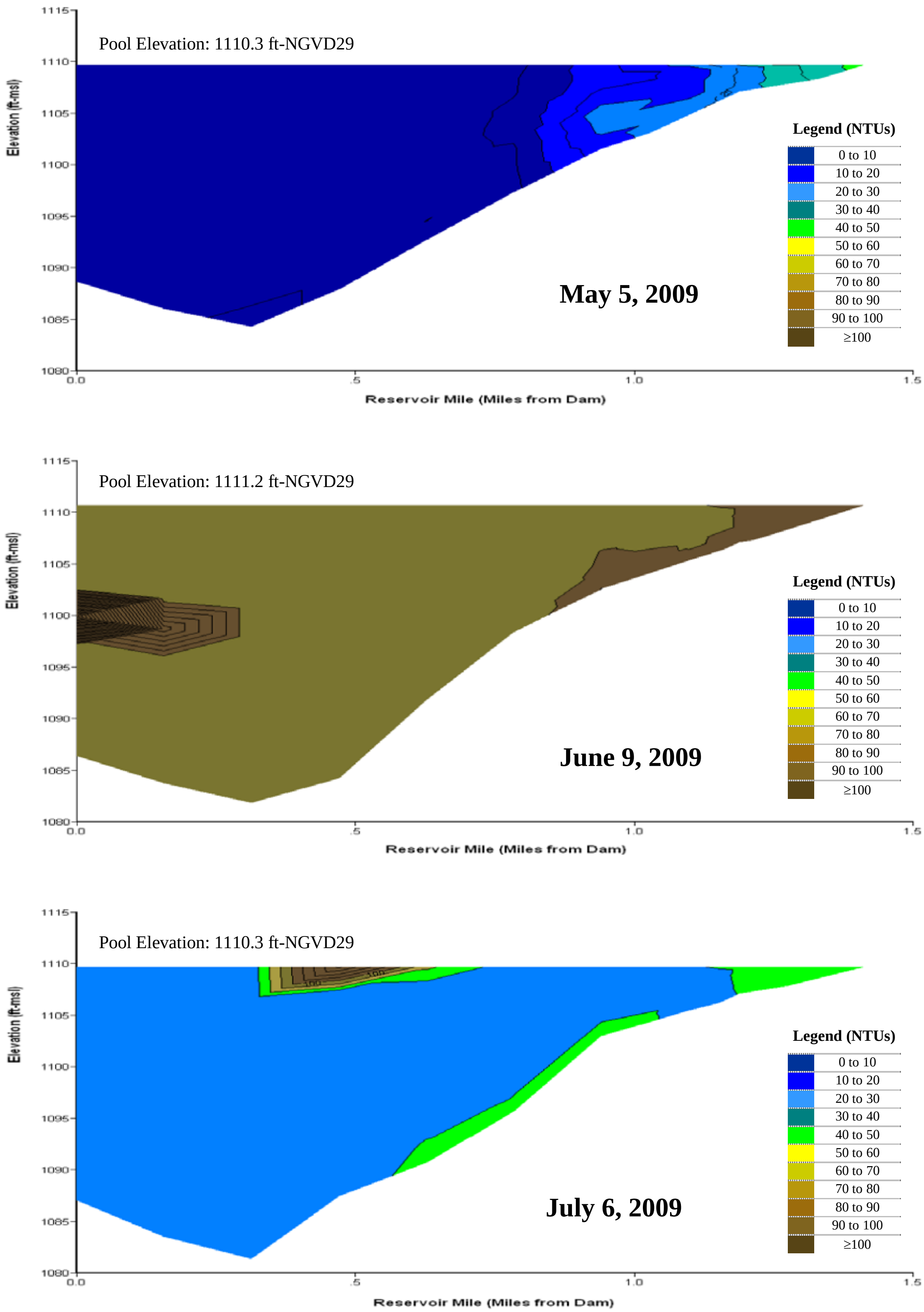
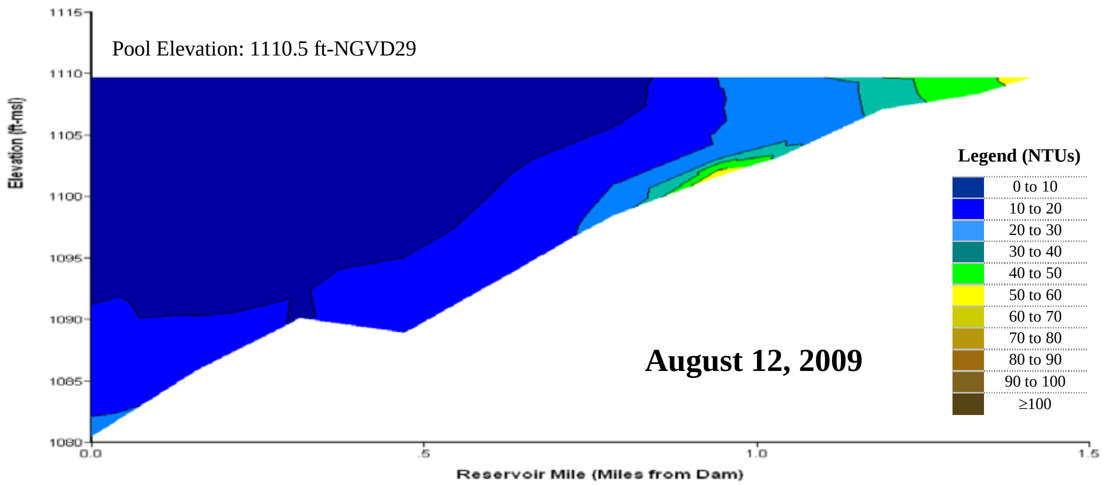


Plate 18. Longitudinal turbidity contour plots of Zorinsky Lake based on depth-profile turbidity levels (NTU) measured from May to September 2009.



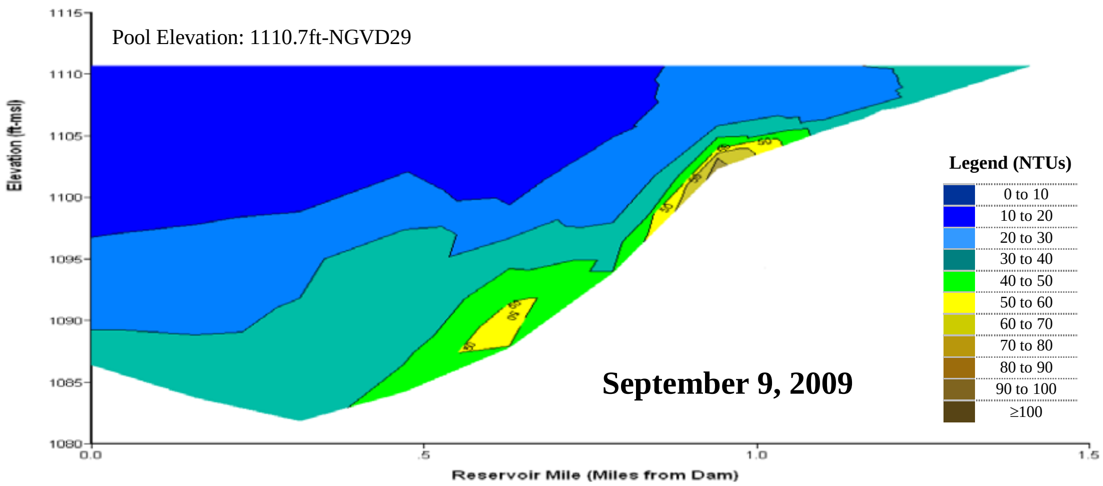


Plate 18. (Continued).

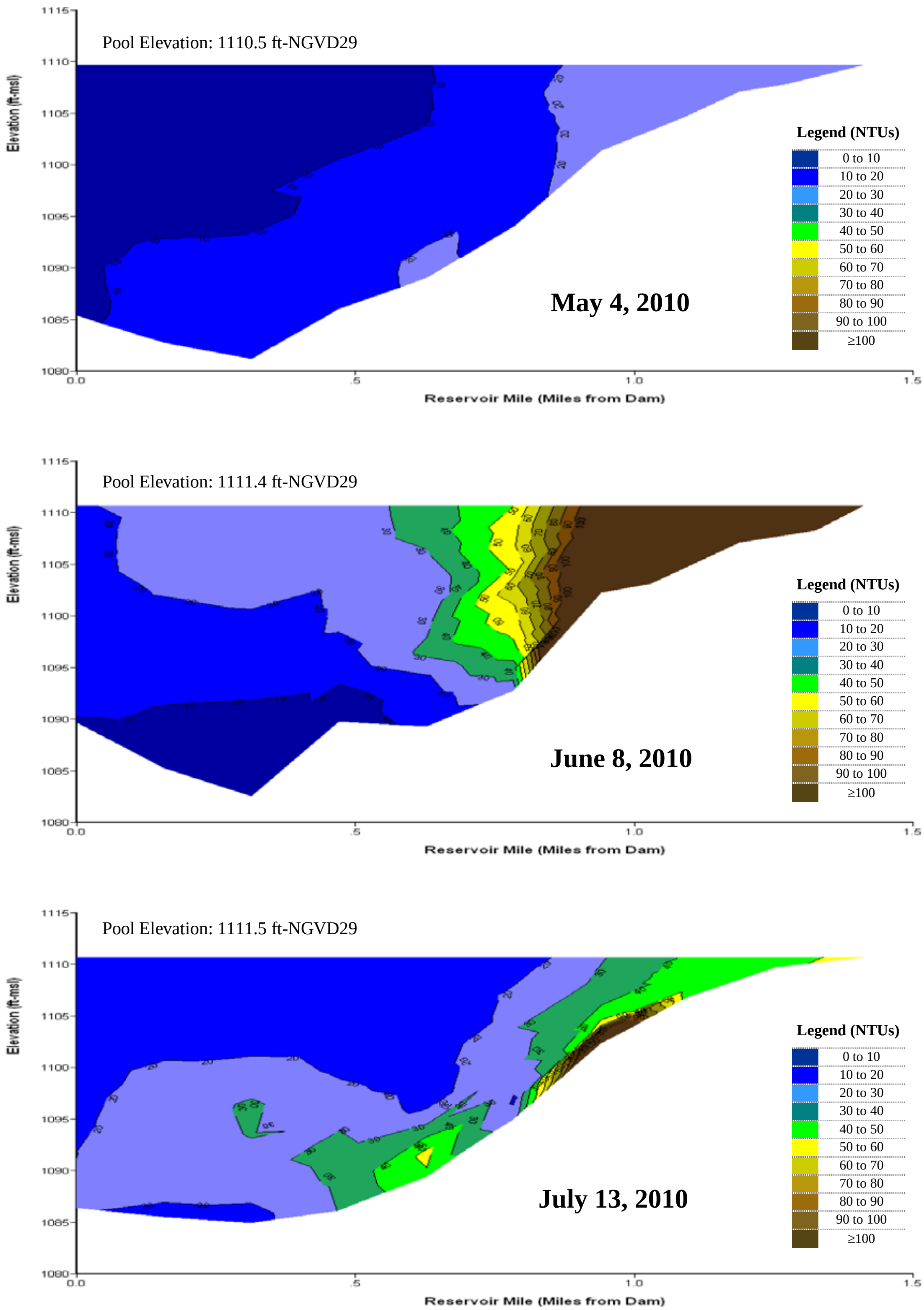
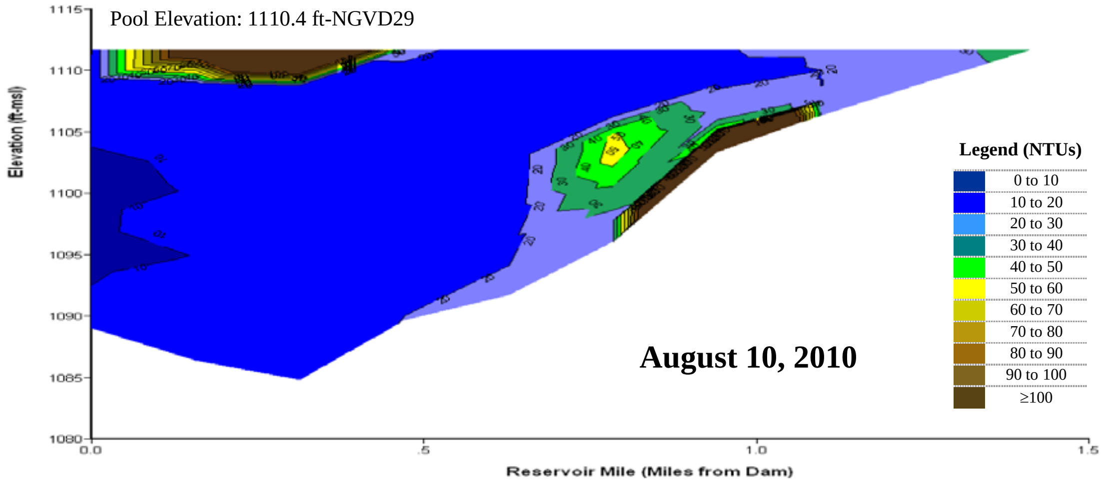


Plate 19. Longitudinal turbidity contour plots of Zorinsky Lake based on depth-profile turbidity levels (NTU) measured at sites EZRLKND1, EZRLKML1A, EZRLKML1B, EZRLKML2, EZRLKUP1, and EZRLKUP2 in 2010.



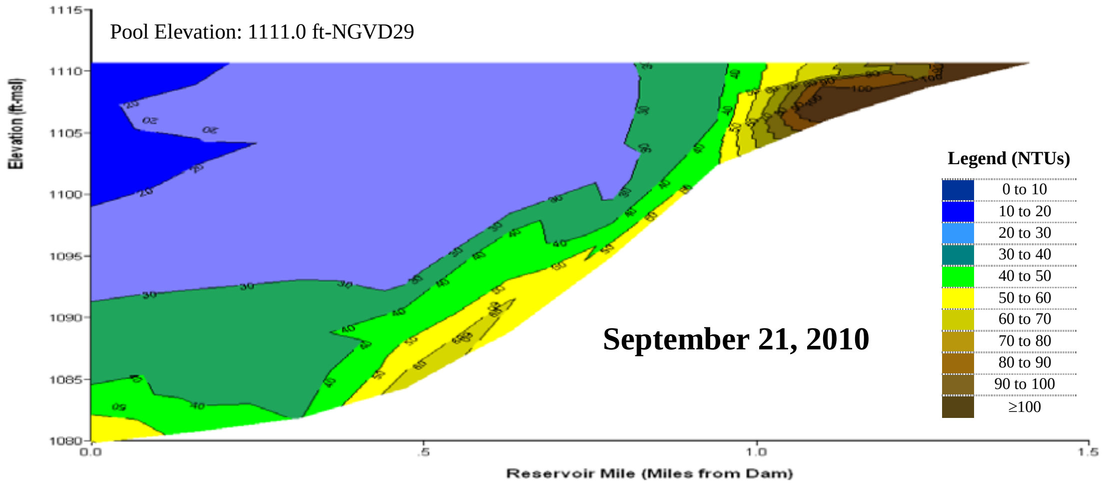


Plate 19. (Continued).

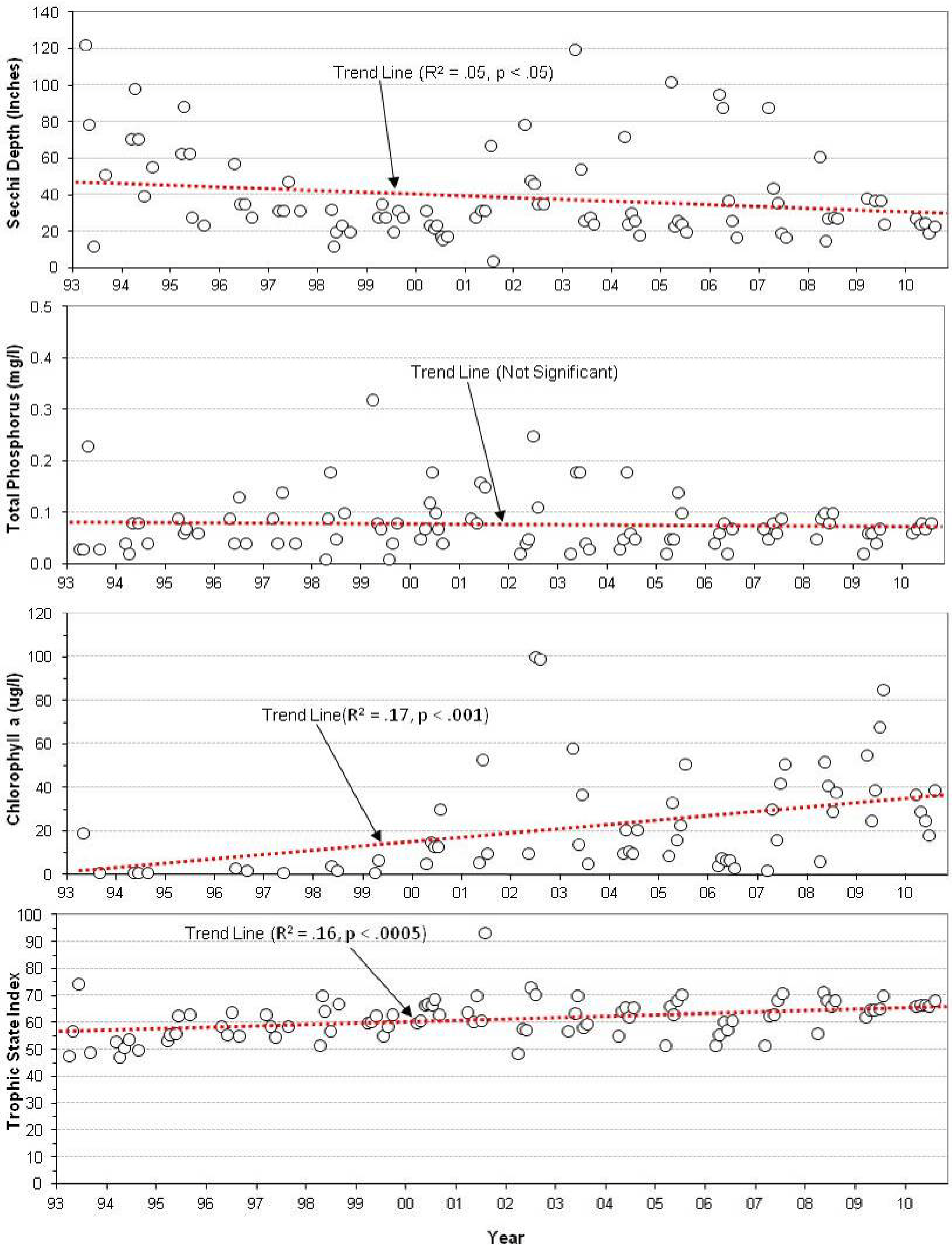


Plate 20. Historic trends for Secchi depth, total phosphorus, chlorophyll *a*, and Trophic State Index (TSI) monitored in Zorinsky Lake at the near-dam, ambient site (i.e., site EZRLKND1) over the 18-year period of 1993 through 2010.

Plate 21. Water quality conditions monitored at Zorinsky Lake through the ice at site EZRLKND1 on 28-Jan-2011.

Depth (ft)	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (% Sat)	pH (SU)	Specific Conductance (uS/cm)	ORP (mV)	Turbidity (NTU)	Chlorophyll a mV (*ug/l*)*
0.1	1.0	0.6	4.6	6.7	820	247	5	0.025 *(7)*
1	0.8	0.6	4.3	6.7	825	247	5	0.052 *(14)*
2	1.8	0.4	3.2	6.6	865	248	5	0.036 *(10)*
3	2.2	0.4	3.0	6.6	889	243	7	0.038 *(10)*
4	2.5	0.4	2.9	6.6	914	240	9	0.037 *(10)*
5	2.8	0.4	2.8	6.6	947	234	11	0.025 *(7)*

* Values in parentheses are estimated chlorophyll *a* concentrations -- see text.

Plate 22. Water quality conditions monitored at Zorinsky Lake through the ice at sites EZRLKML2, EZRLKML1B, EZRLKML1A, and EZRLKND1 on 4-Feb-2011.

Depth (ft)	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (% Sat)	pH (SU)	Specific Conductance (uS/cm)	ORP (mV)	Turbidity (NTU)	Chlorophyll a mV (*ug/l*)*
Site: EZRLKML2								
0.1	0.3	9.6	67.5	7.2	1,045	238	45	0.009 *(3)*
1	0.2	9.1	63.6	7.1	1,043	225	38	0.010 *(3)*
2	0.2	9.0	62.9	7.1	1,043	219	28	0.010 *(3)*
3	0.2	8.9	62.8	7.1	1,046	217	53	0.012 *(3)*
Site: EZRLKML1B								
0.1	0.1	4.4	30.5	6.8	1,021	304	22	0.111 *(31)*
1	0.3	2.9	20.1	6.7	989	303	24	0.537 *(148)*
2	0.5	2.1	15.0	6.7	985	301	17	0.597 *(164)*
3	0.6	3.1	21.9	6.8	1,094	297	18	0.015 *(4)*
4	0.9	3.6	25.7	6.8	1,136	262	26	0.052 *(14)*
5	1.5	2.2	16.1	6.7	1,162	212	33	0.035 *(10)*
6	1.3	1.4	9.9	6.7	1,233	199	37	0.020 *(6)*
7	1.2	0.8	5.6	6.7	1,357	195	36	0.021 *(6)*
8	1.7	0.5	3.8	6.5	1,895	153	-----	----- -----
Site: EZRLKML1A								
0.1	0.1	3.0	20.8	7.0	948	294	14	0.167 *(46)*
1	0.5	1.3	9.1	6.9	936	289	30	0.128 *(35)*
2	1.1	0.9	6.6	6.8	1,014	283	47	0.052 *(14)*
3	1.4	0.6	4.3	6.8	1,052	264	43	0.035 *(10)*
4	1.6	0.5	3.4	6.8	1,112	237	40	0.022 *(6)*
5	1.5	0.4	3.1	6.8	1,256	221	40	0.017 *(5)*
6	1.5	0.4	3.0	6.8	1,301	215	39	0.018 *(5)*
7	1.2	0.8	5.6	6.8	1,453	219	36	0.015 *(4)*
8	1.1	1.0	6.9	6.8	1,583	225	34	0.015 *(4)*
9	1.0	1.2	8.5	6.8	1,679	229	31	0.015 *(4)*
10	1.1	1.6	11.7	6.8	1,806	233	27	0.014 *(4)*
11	1.4	1.7	12.5	6.8	1,852	223	25	0.012 *(3)*
12	2.1	0.8	5.8	6.9	1,931	118	-----	----- -----
Site: EZRLKND1								
0.1	0.5	1.7	11.7	6.8	898	201	28	0.012 *(3)*
1	0.9	0.9	6.5	6.8	865	191	7	0.014 *(4)*
2	2.1	0.7	4.8	6.8	935	194	10	0.030 *(8)*
3	2.9	0.5	3.7	6.8	1,000	189	14	0.040 *(11)*
4	2.8	0.4	3.2	6.8	1,021	182	15	0.041 *(11)*
5	3.1	0.4	3.0	6.8	1,050	160	17	0.034 *(9)*
6	3.3	0.4	2.8	6.8	1,099	144	17	0.026 *(7)*

* Values in parentheses are estimated chlorophyll *a* concentrations -- see text.

Plate 23. Water quality conditions monitored at Zorinsky Lake through the ice at sites EZRLKML2, EZRLKML1B, EZRLKML1A, and EZRLKND1 on 11-Feb-2011.

Depth (ft)	Temperature (°C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen (% Sat)	pH (SU)	Specific Conductance (uS/cm)	ORP (mV)	Turbidity (NTU)	Chlorophyll a mV (*ug/l*)*
Site: EZRLKML2								
0.1	0.4	9.0	63.9	7.0	1,209	205	76	0.016 *(4)*
1	0.4	9.0	63.5	7.0	1,204	203	67	0.016 *(4)*
2	0.3	8.9	63.1	7.0	1,194	204	63	0.031 *(9)*
3	0.4	8.5	60.4	7.0	1,188	199	94	0.037 *(10)*
Site: EZRLKML1B								
0.1	0.6	3.6	25.8	7.0	1,109	285	12	0.453 *(124)*
1	0.5	3.2	22.8	6.9	1,115	287	11	0.415 *(114)*
2	0.7	2.6	18.2	6.9	1,113	283	15	0.353 *(97)*
3	0.8	2.5	17.6	6.9	1,154	282	16	0.247 *(65)*
4	0.6	3.9	28.0	6.9	1,301	278	19	0.106 *(29)*
5	0.8	5.0	36.0	6.9	1,371	266	24	0.066 *(18)*
6	0.8	4.3	30.8	6.9	1,563	260	24	0.038 *(11)*
7	1.0	3.3	23.6	6.9	1,671	246	23	0.022 *(9)*
8	1.3	2.5	18.2	6.9	2,219	235	22	0.029 *(7)*
Site: EZRLKML1A								
0.1	0.4	3.6	25.5	6.9	1,100	286	76	0.386 *(106)*
1	0.4	2.5	17.7	6.9	1,095	288	58	0.457 *(126)*
2	0.5	1.6	11.7	6.8	1,100	289	19	0.413 *(114)*
3	0.9	0.8	5.6	6.8	1,120	272	15	0.133 *(37)*
4	1.4	0.7	4.7	6.8	1,203	245	15	0.035 *(10)*
5	1.5	0.5	3.5	6.8	1,336	211	19	0.022 *(6)*
6	1.4	0.4	2.7	6.8	1,564	194	19	0.016 *(4)*
7	1.4	0.4	2.6	6.8	1,642	191	19	0.014 *(4)*
8	1.2	0.5	3.4	6.8	1,776	191	21	0.012 *(3)*
9	1.0	2.2	15.9	6.9	2,124	198	20	0.013 *(4)*
10	1.1	3.2	23.0	7.0	2,621	208	16	0.014 *(4)*
11	1.3	3.2	23.6	7.0	2,726	211	14	0.013 *(4)*
12	1.7	2.6	19.3	6.9	2,840	208	13	0.018 *(5)*
Site: EZRLKND1								
0.1	0.8	2.2	15.5	6.9	1,056	162	12	0.011 *(3)*
1	0.9	2.1	15.1	6.9	1,027	161	12	0.012 *(3)*
2	1.2	1.3	9.3	6.8	1,005	160	11	0.018 *(5)*
3	2.6	0.7	5.0	6.8	1,079	148	9	0.032 *(9)*
4	3.0	0.4	3.2	6.8	1,106	134	7	0.032 *(9)*
5	3.0	0.4	2.7	6.8	1,274	119	7	0.019 *(5)*
6	3.2	0.3	2.6	6.8	1,302	113	9	0.018 *(5)*

* Values in parentheses are estimated chlorophyll *a* concentrations -- see text.

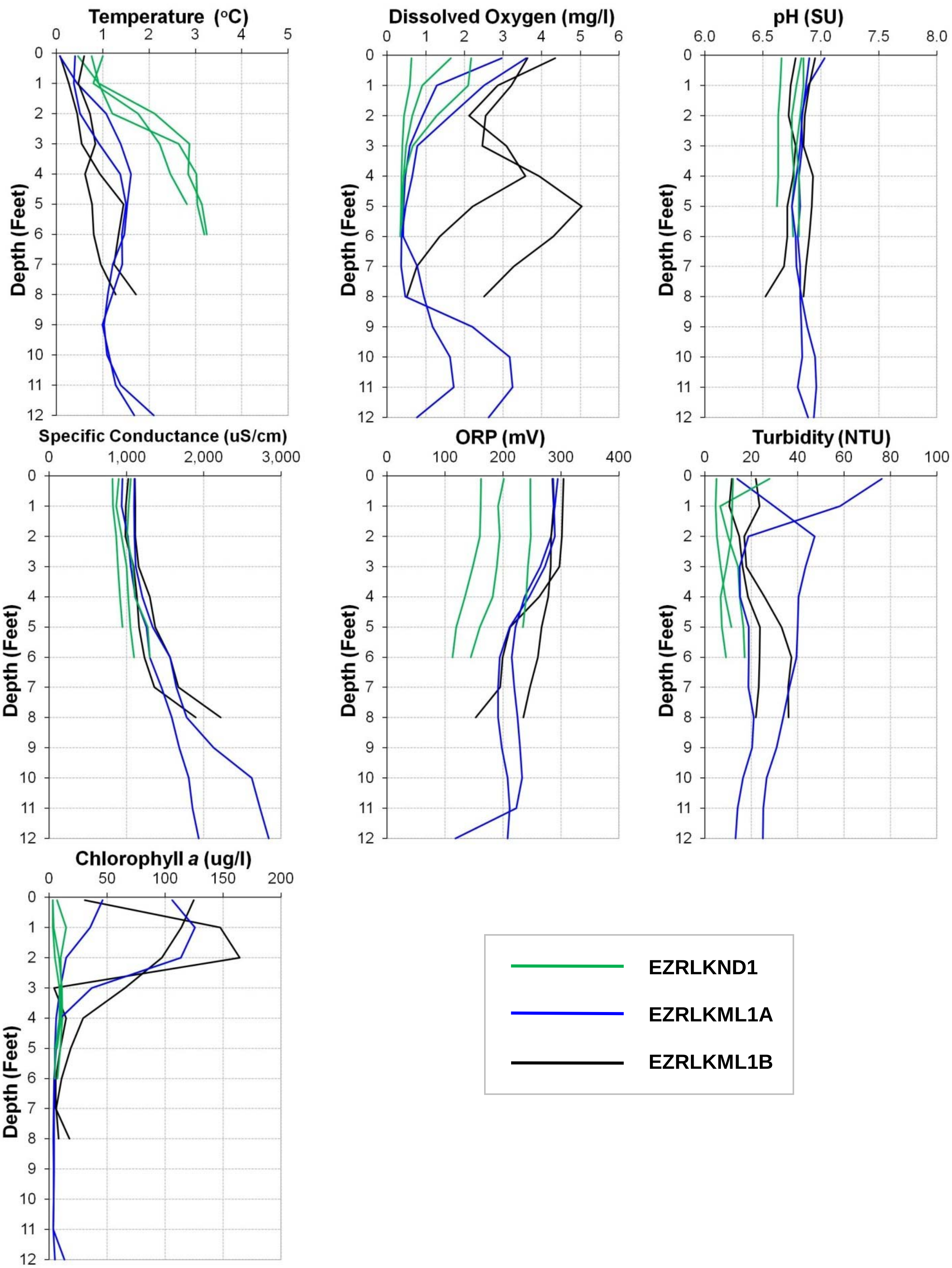


Plate 24. Depth profiles measured at sites EZRLKND1, EZRLKML1A, and EZRLKML1B on 28-Jan, 4-Feb, and 11-Feb 2011

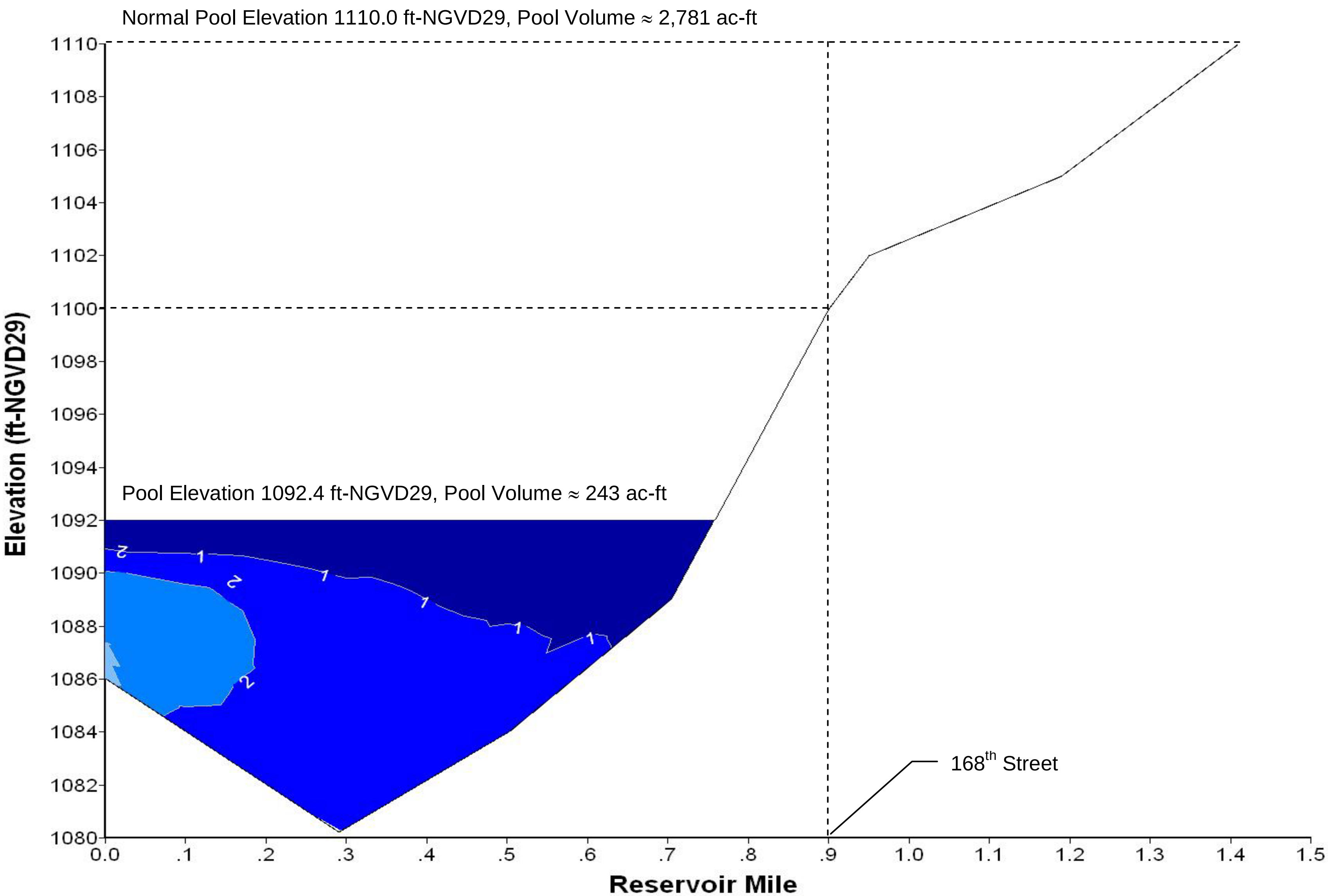


Plate 25. Longitudinal temperature (°C) contour plot of Zorinsky Lake based on depth profiles measured on 4-February 2011.

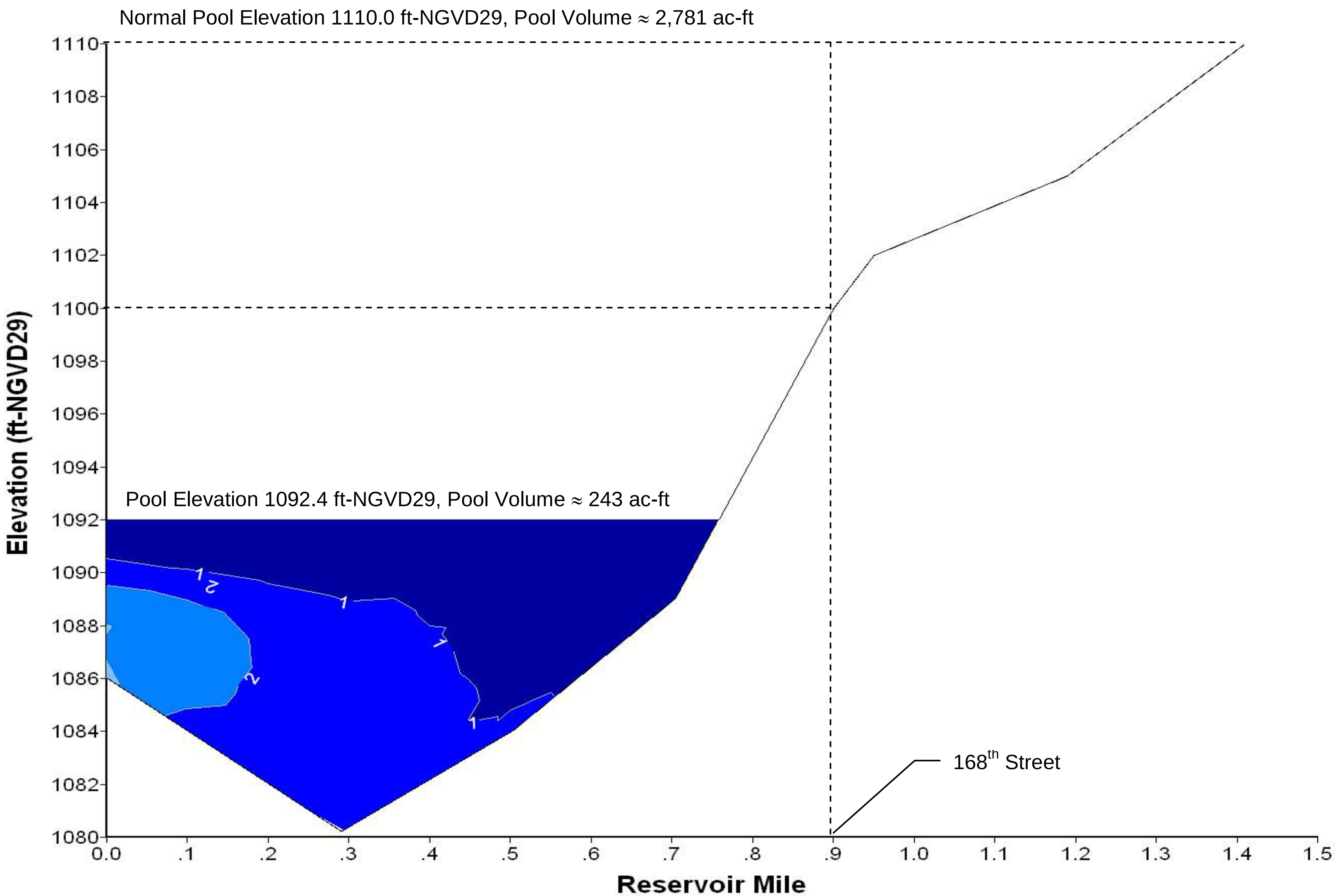


Plate 26. Longitudinal temperature (°C) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

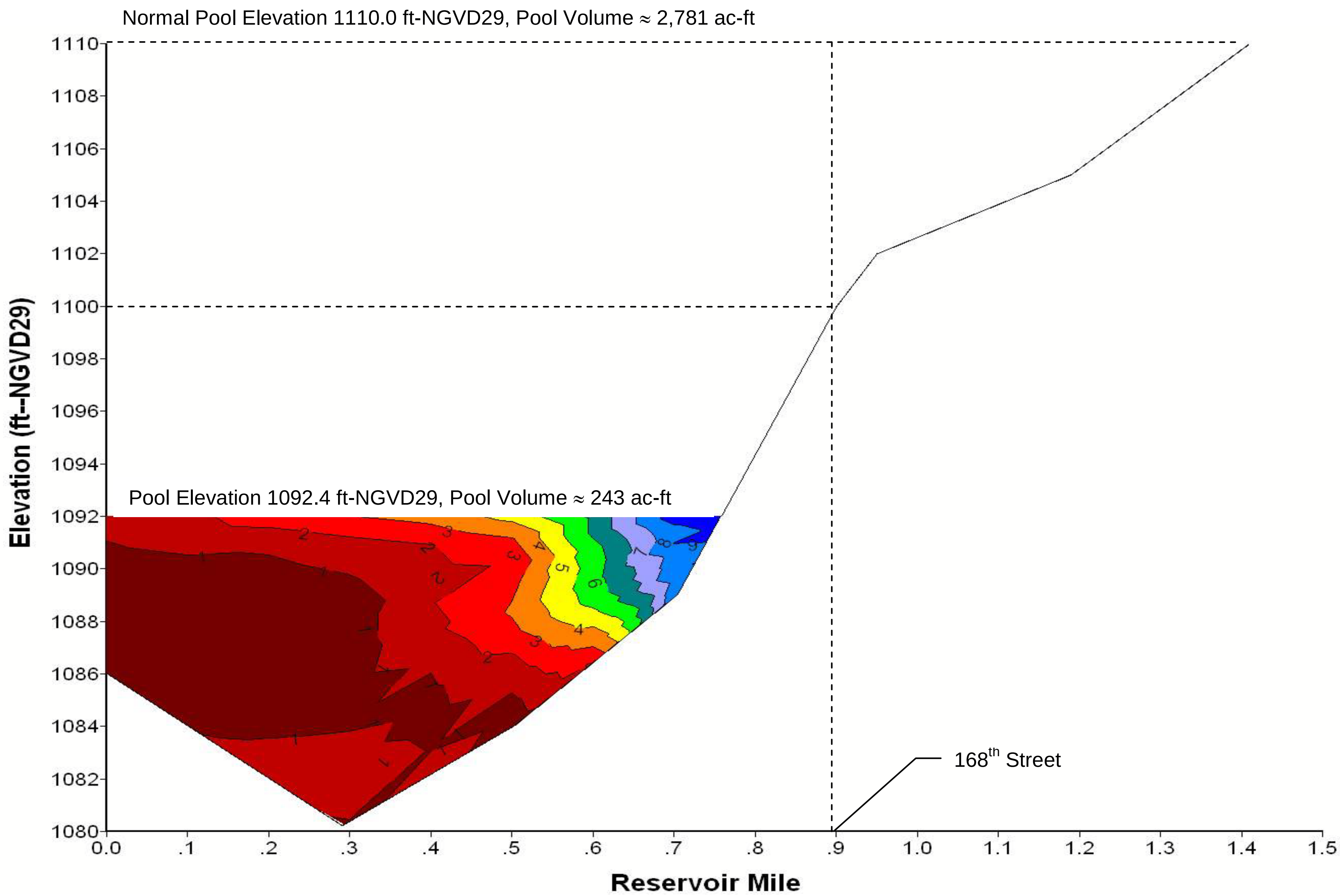


Plate 27. Longitudinal dissolved oxygen (mg/l) contour plot of Zorinsky Lake based on depth profiles measured on 4-February-2011.

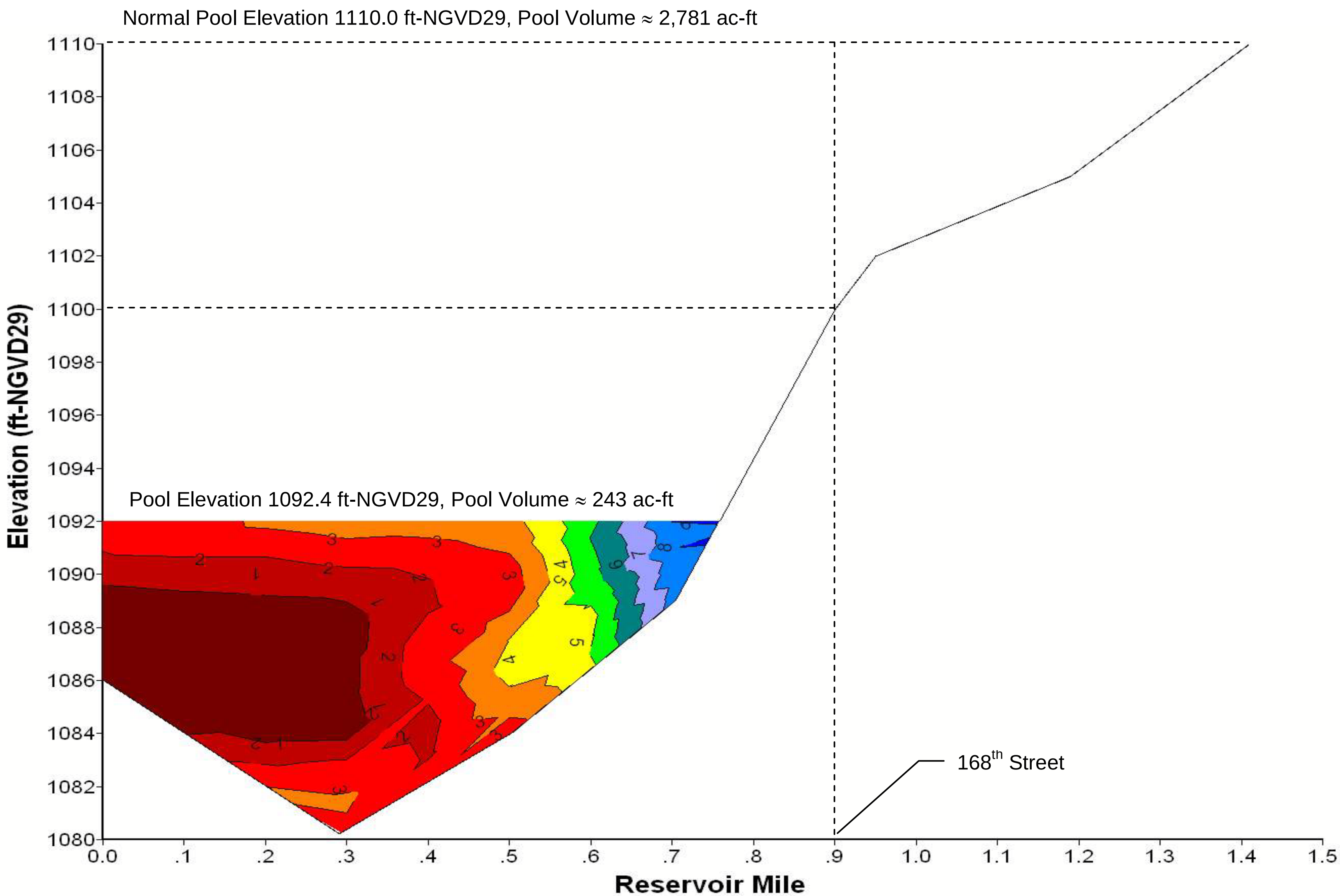


Plate 28. Longitudinal dissolved oxygen (mg/l) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

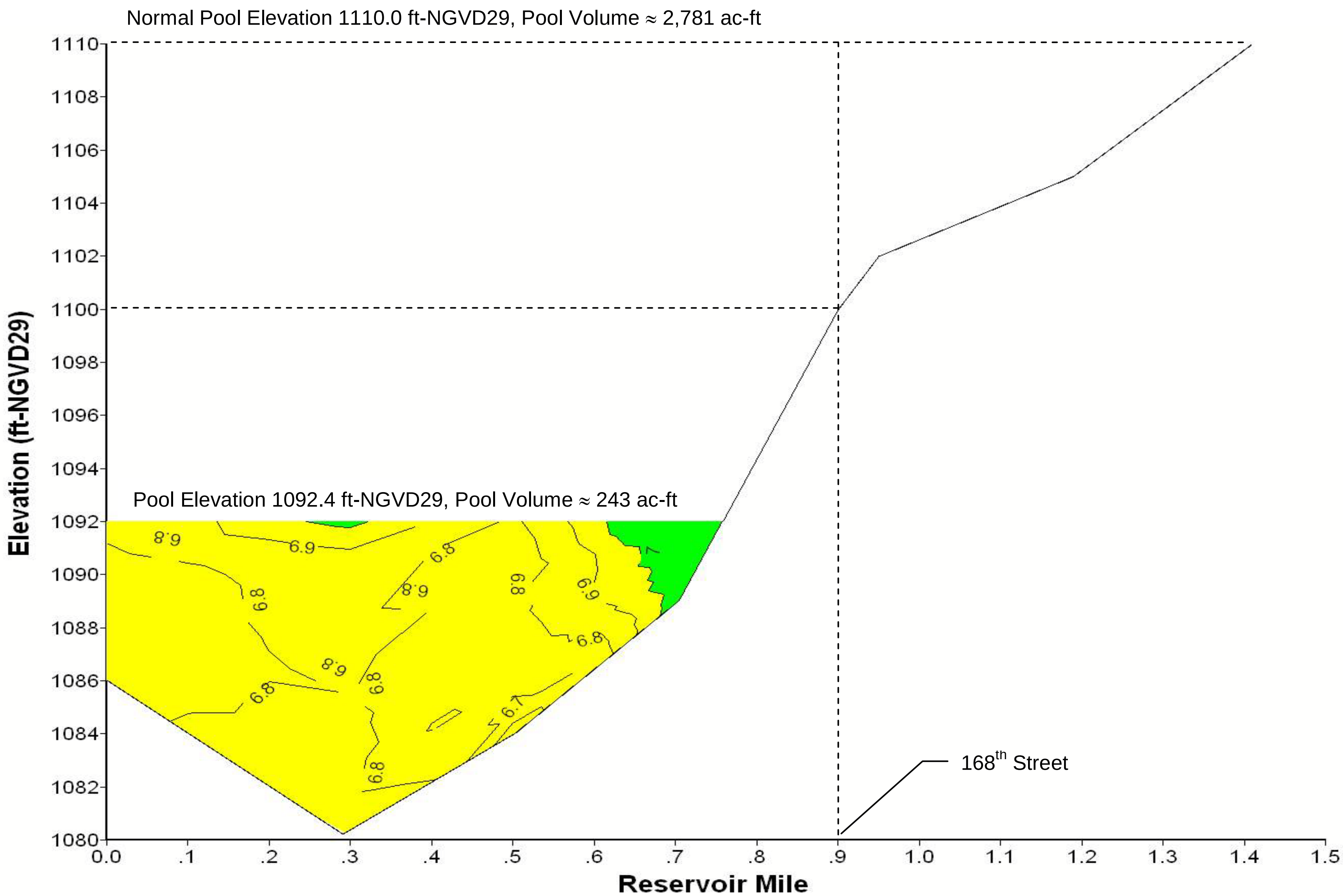


Plate 29. Longitudinal pH (SU) contour plot of Zorinsky Lake based on depth profiles measured on 4-February-2011.

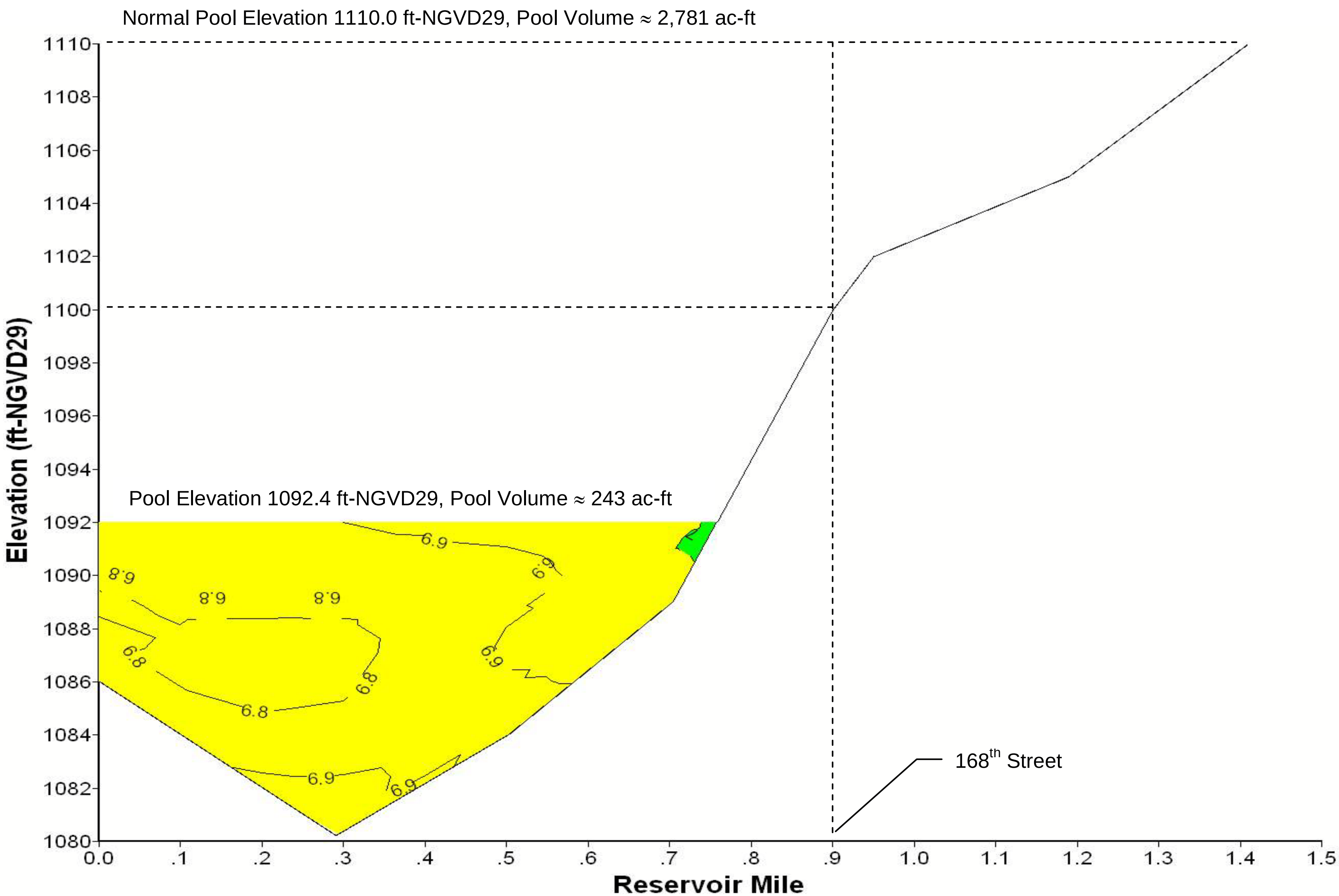


Plate 30. Longitudinal pH (SU) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

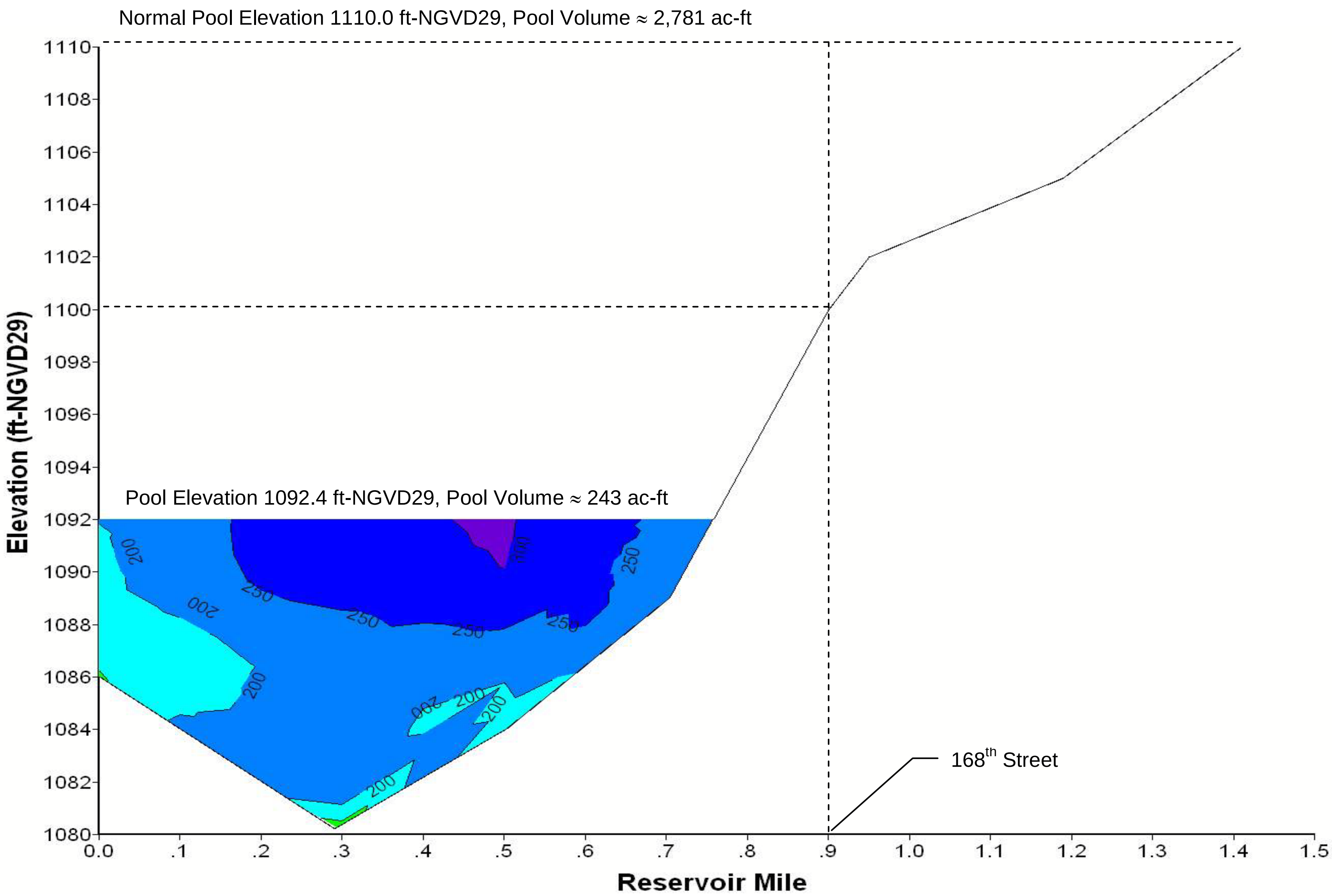


Plate 31. Longitudinal oxidation-reduction potential (mV) contour plot of Zorinsky Lake based on depth profiles measured on 4-February-2011.

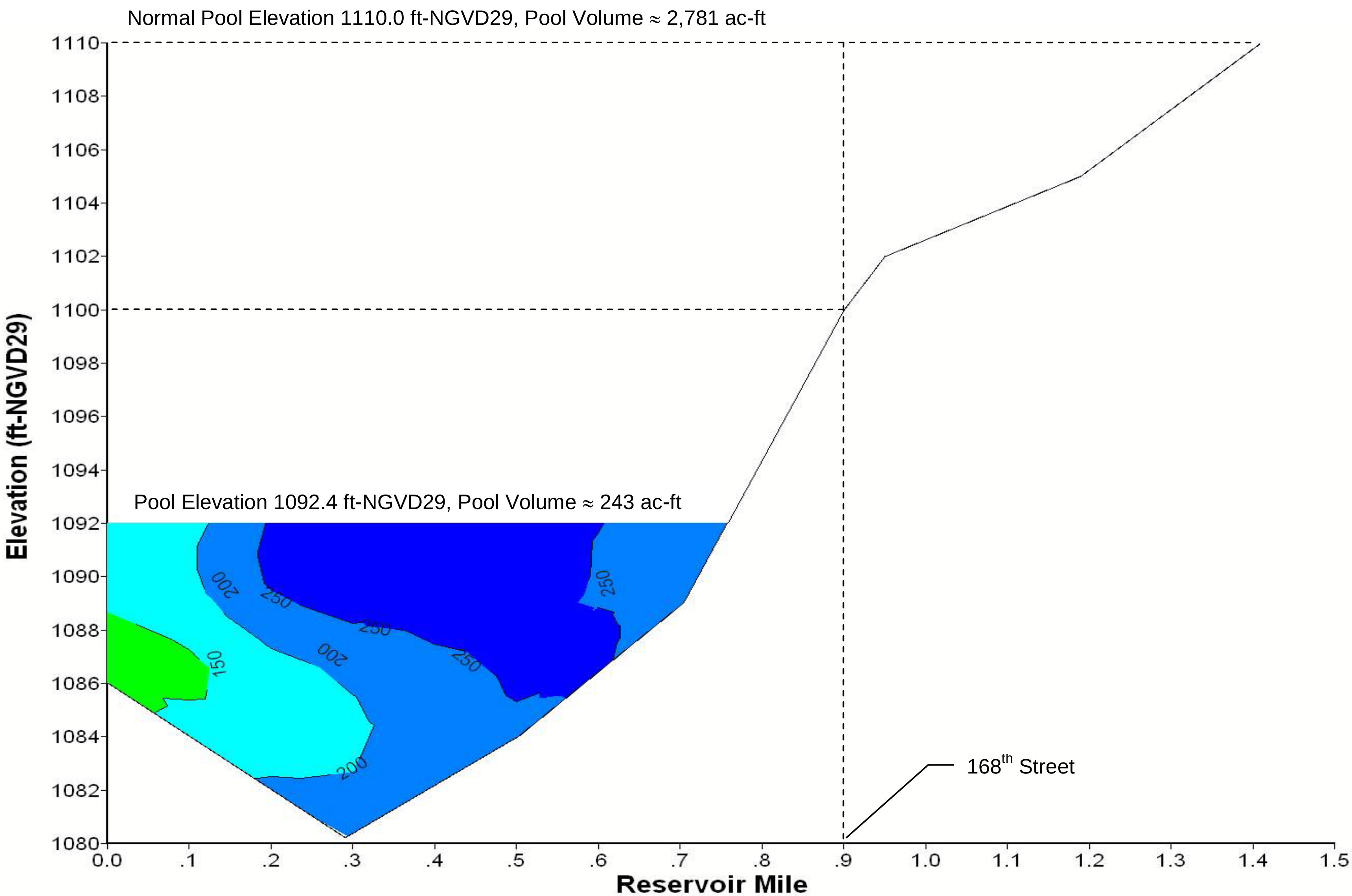


Plate 32. Longitudinal oxidation-reduction potential (mV) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

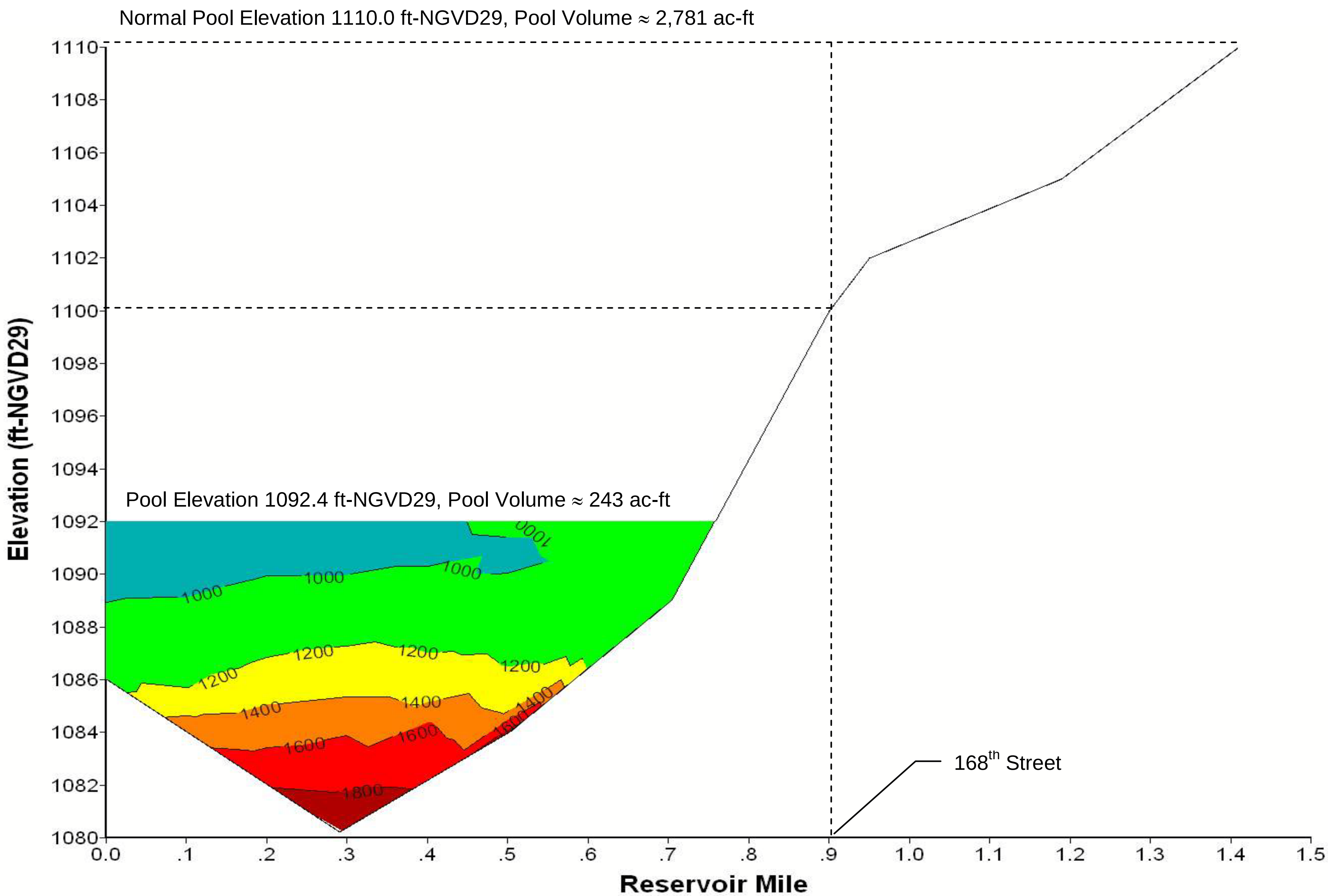


Plate 33. Longitudinal specific conductance (uS/cm) contour plot of Zorinsky Lake based on depth profiles measured on 4-February-2011.

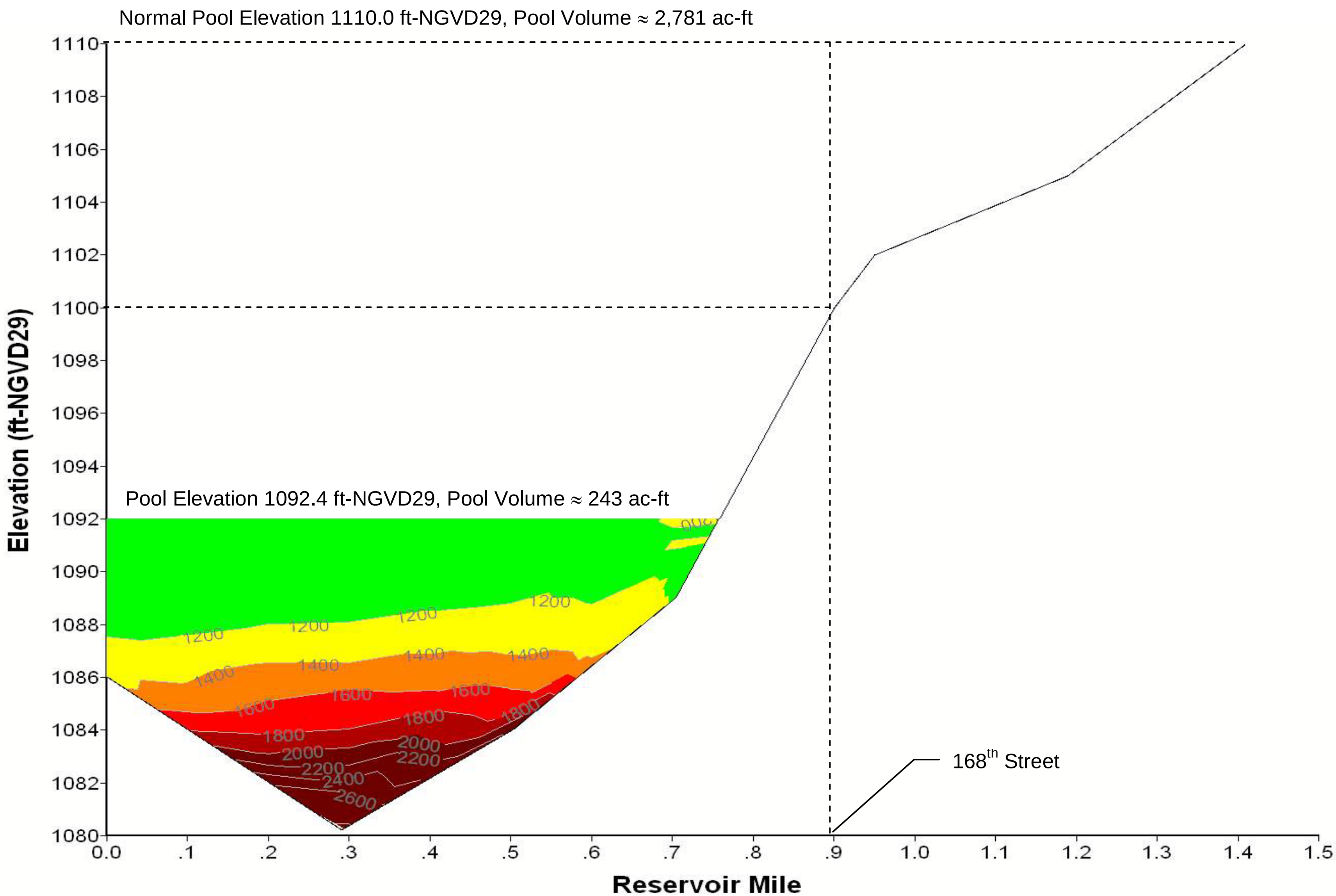


Plate 34. Longitudinal specific conductance (uS/cm) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

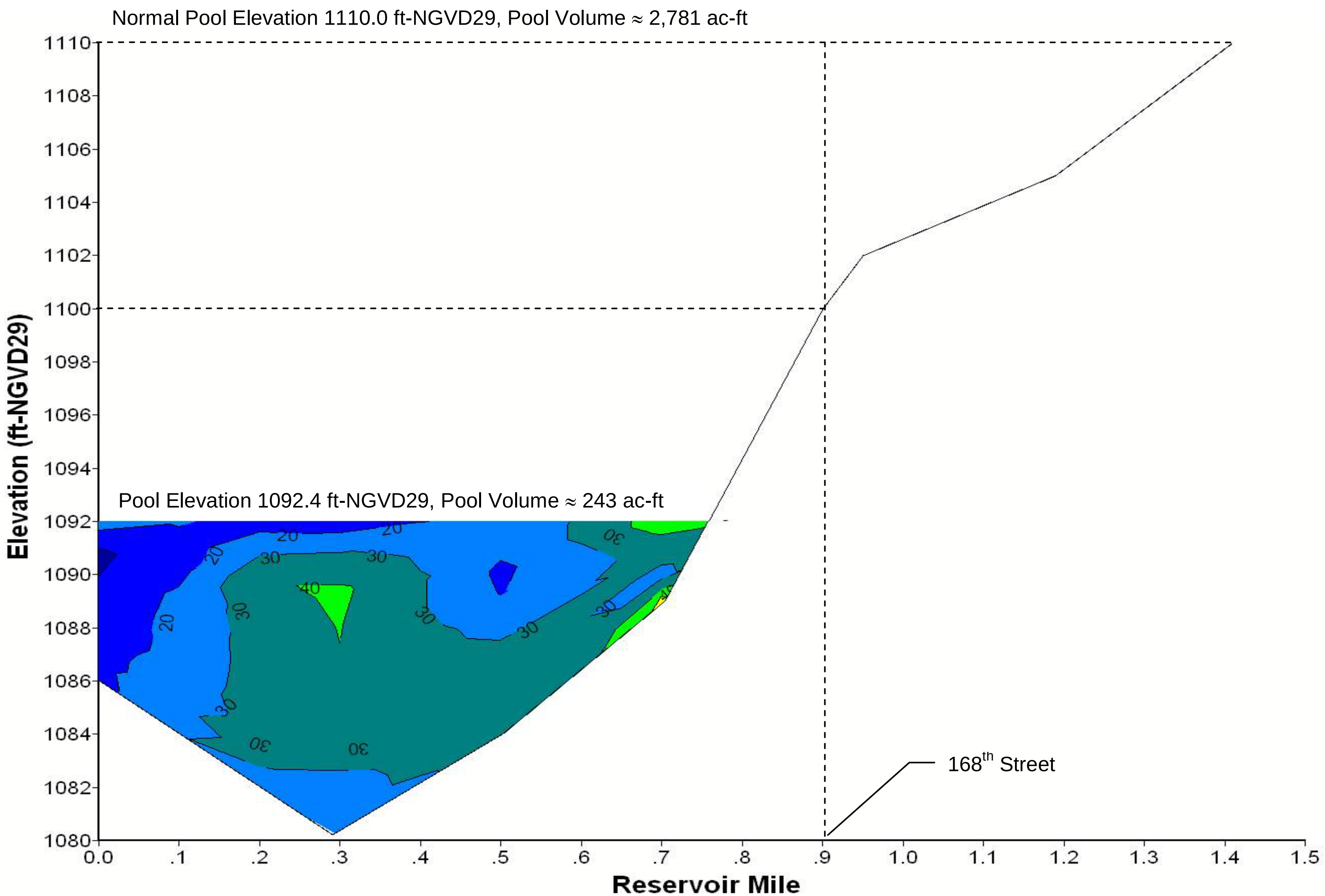


Plate 35. Longitudinal turbidity (NTU) contour plot of Zorinsky Lake based on depth profiles measured on 4-February-2011.

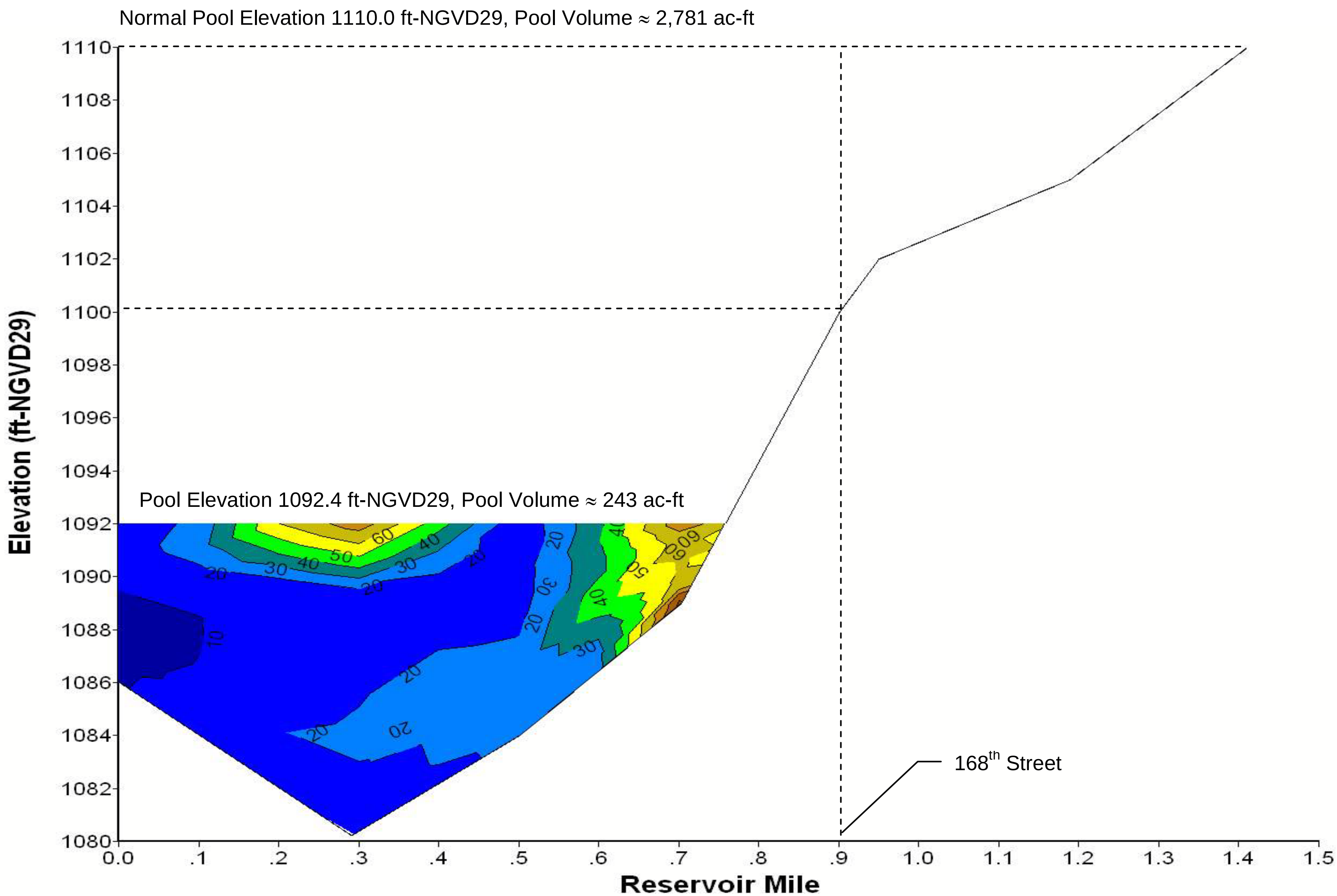


Plate 36. Longitudinal turbidity (NTU) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

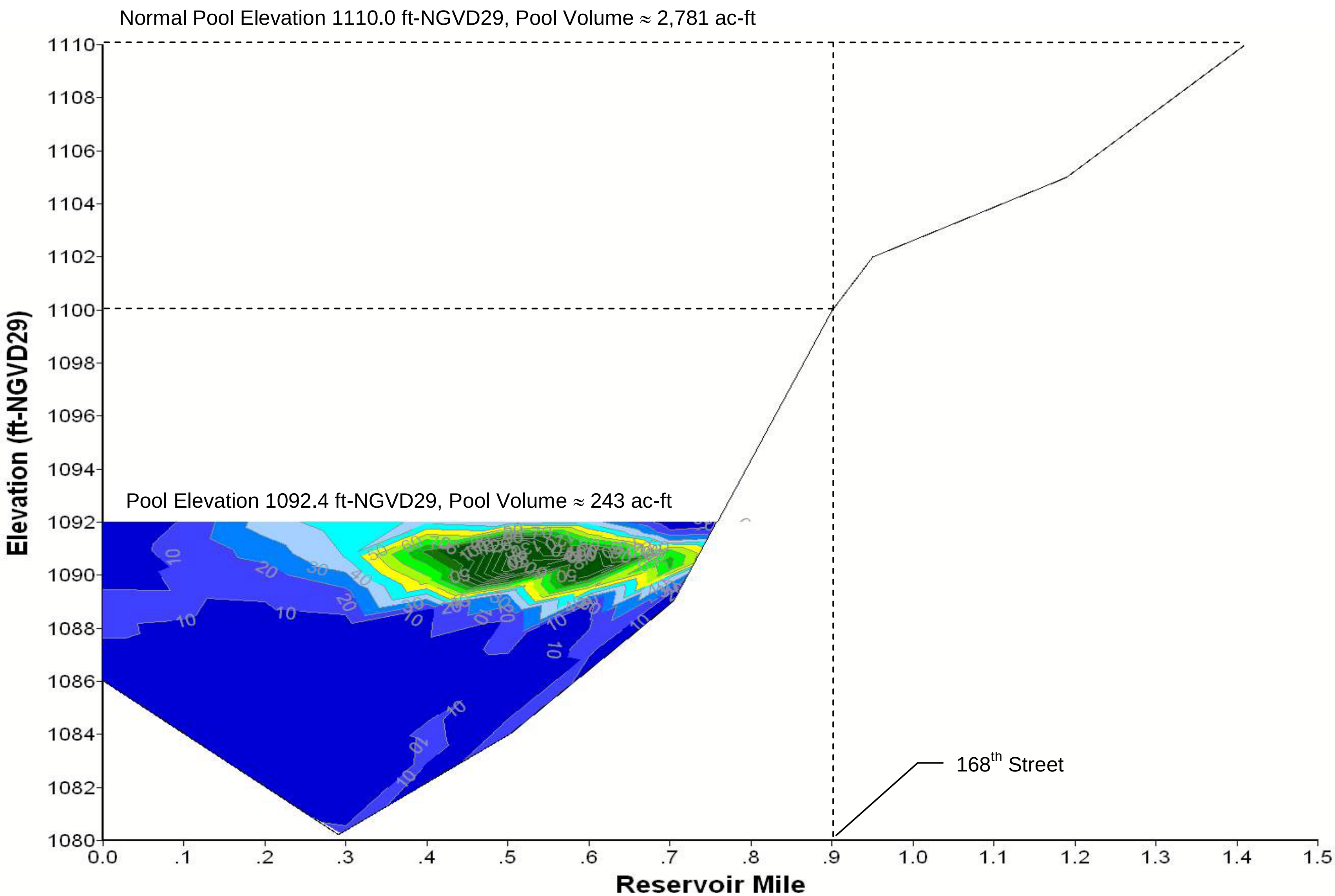


Plate 37. Longitudinal chlorophyll *a* (ug/l) contour plot of Zorinsky Lake based on depth profiles measured on 4-February-2011.

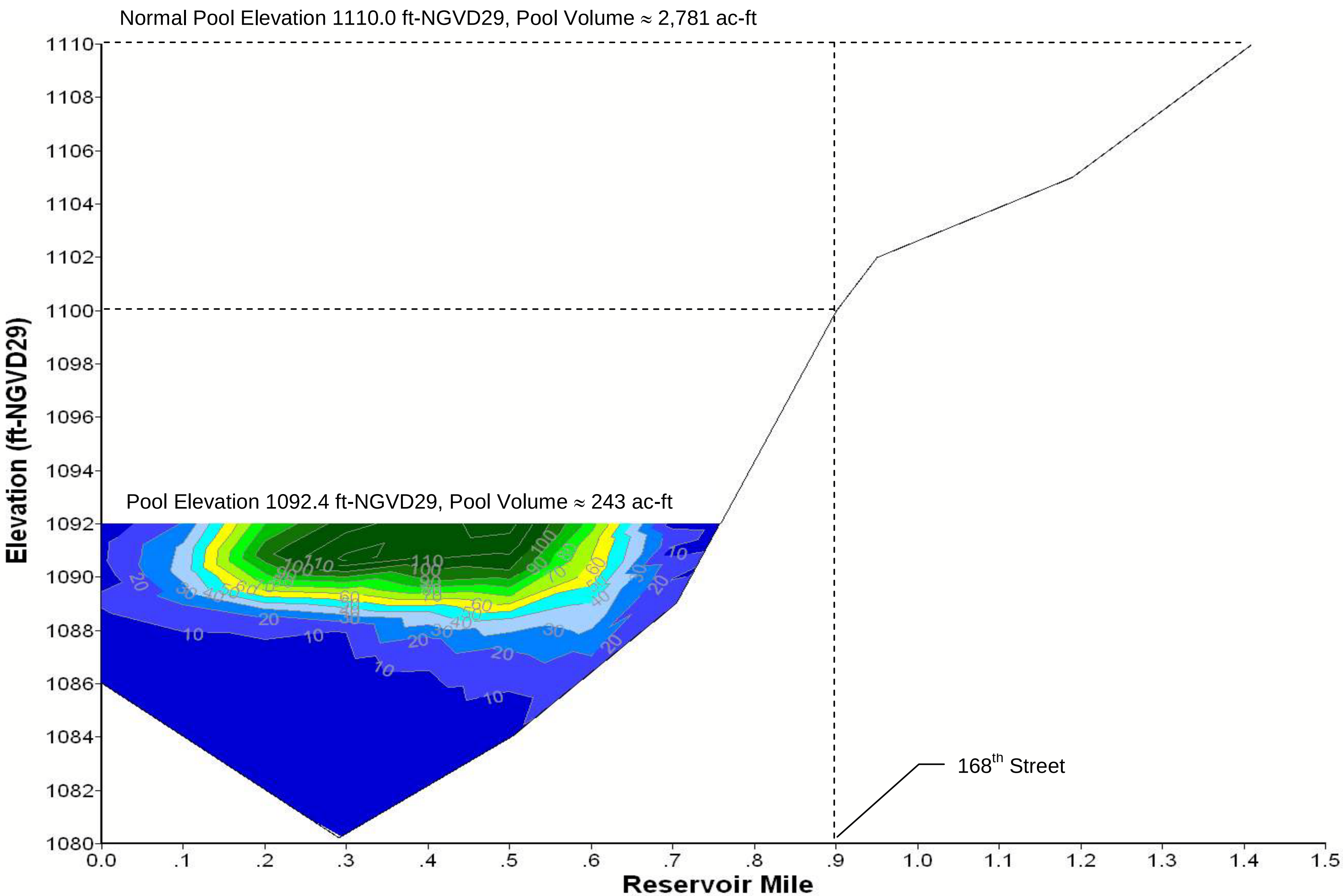


Plate 38. Longitudinal chlorophyll *a* (ug/l) contour plot of Zorinsky Lake based on depth profiles measured on 11-February-2011.

Aerial view of Zorinsky Lake on 22-Feb-2011 after the complete 2010/2011 winter drawdown

Plate 39. Delineation and prioritization of areas for inspection for the occurrence of adult zebra mussel shells on the emerged reservoir bottom of Zorinsky Lake.
Priority of delineated areas for inspection was Red = Highest, Green = Second Highest, and White = Lowest.